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RESISTANCE CHARACTERISTICS OF THE HIGH SPEED TRANSOM STERN SHIP R/V ATHENA
IN THE BARE HULL CONDITION, REPRESENTED BY DTNSRDC MODEL 5365

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

RESISTANCE CHARACTERISTICS OF THE HIGH SPEED TRANSOM STERN SHIP R/V ATHENA IN THE BARE HULL CONDITION, REPRESENTED BY DTNSRDC MODEL 5365

by

Douglas S. Jenkins

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SHIP PERFORMANCE DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

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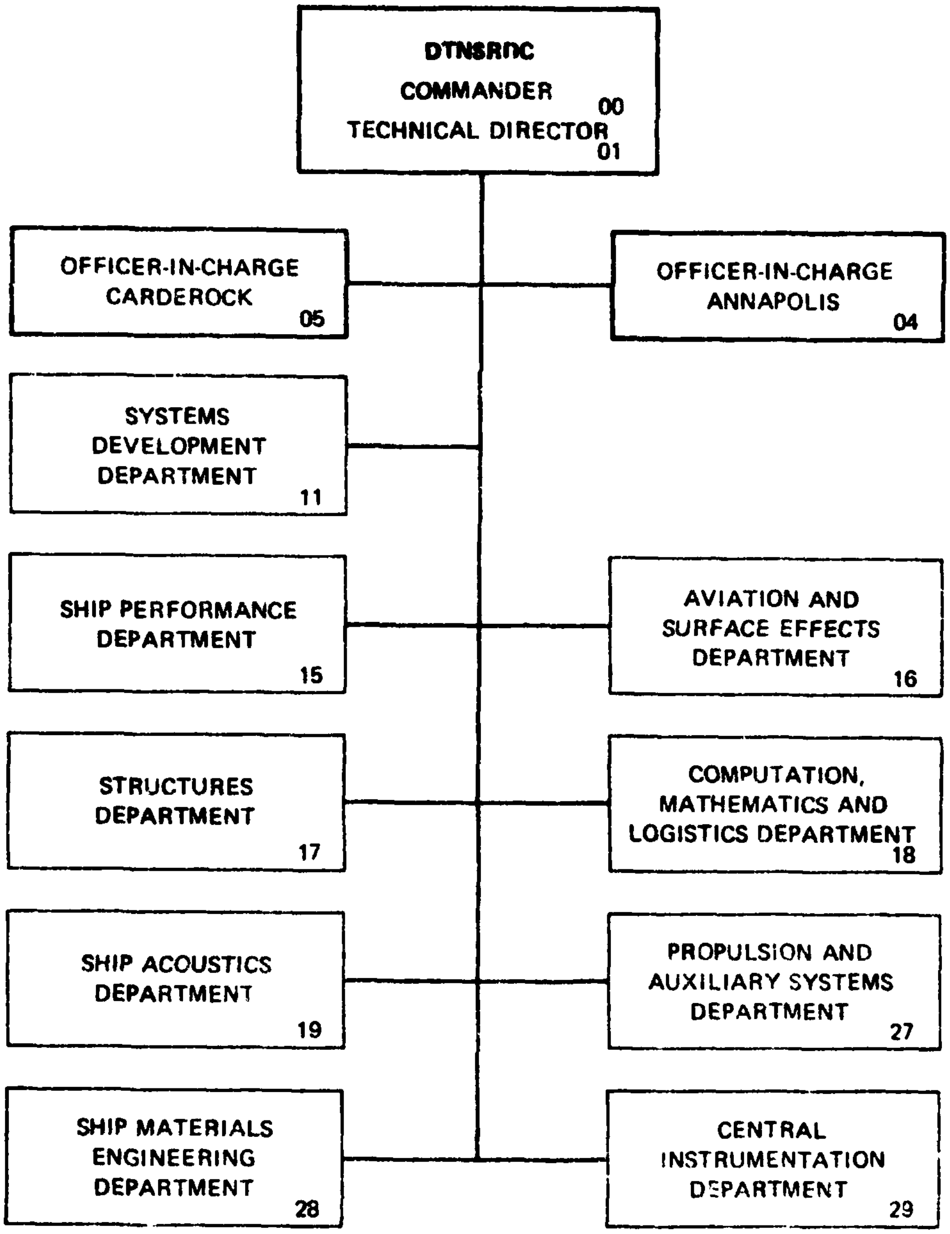

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Towing tank experiments were conducted on a 1/8.25-scale model of the high-speed transom stern ship, R/V ATHENA, in order to provide data for comparison and evaluation of various analytical predictions. Measurements of total resistance, wave pattern resistance, bow and stern sinkage and wave heights along and behind the hull were made over a Froude number range of 0.28 to 1.00 with the model free to sink and trim, and captive

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at zero trim and sinkage. These measurements are compared with an analytical prediction and with measurements made on a 1/14.67-scale model. The wave pattern resistance coefficients of the two scale models agree well between Froude numbers of 0.28 and 0.65. The analytically predicted wave resistance values exceed the measured wave pattern resistance values. The residuary resistance coefficients of the large model are similar in trend to those of the small model for $F_n^* > 0.35$, and are less than the predicted analytical values throughout the speed range. The presence of a stern wedge on the large model results in less sinkage and trim and slightly smaller values of residuary resistance at Froude numbers above 0.35, when compared to the analytical results and the experimental results of the small model. The reported measurements provide a basis for the evaluation of future analytical computations of resistance characteristics for high-speed transom stern ships.

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NOMENCLATURE*

AP Aft perpendicular

A_X Area of midship section

B Beam at midship

B_{max} Maximum beam at 1.00 water line

b Half beam, $b = B/2$

$C_{1,2,3}$ Resist'nce correction factors (see Figure 5)

C Resista Coefficient, $C = R/(\frac{1}{2}\rho U^2 S_0)$ (with subscripts: F for frictio , R for residuary, T for total, W for wavemaking, and WP for wave pattern)

C_B Block coefficient, $C_B = V/L_{pp}BH$

C_F Frictional drag coefficient from the 1957 ITTC ship-model correlation line

C_{PR} Prismatic coefficient, $C_{PR} = V/A_X L_{pp}$

C_{sa} Aft perpendicular sinkage coefficient, $C_{sa} = h(\ell)/\ell$, where $(+)C_{sa}$ is rise

C_{sf} Forward perpendicular sinkage coefficient, $C_{sf} = h(-\ell)/\ell$, where $(+)\ C_{sf}$ is rise

C_S Wetted surface coefficient, $C_S = S_0/L_{pp}(2H + B)$

C_s Midship sinkage coefficient, $C_s=(C_{sf}-C_{sa})/2$, where $(+)C_s$ is rise

C_X Midship sectional area coefficient, $C_X = A_X/BH$

C_τ Trim coefficient, $C_\tau = C_{sf} - C_{sa}$, where $(+)C_\tau$ is bow up

F_n Froude number, $F_n = U/(gL)^{1/2}$

FP Forward perpendicular

g Gravitational acceleration, $g = 32.174\ ft/sec^2$ ($9.807\ m/sec^2$)

H Draft of ship

h(x) Vertical distance between x-axis and x'-axis (positive above undisturbed free surface)

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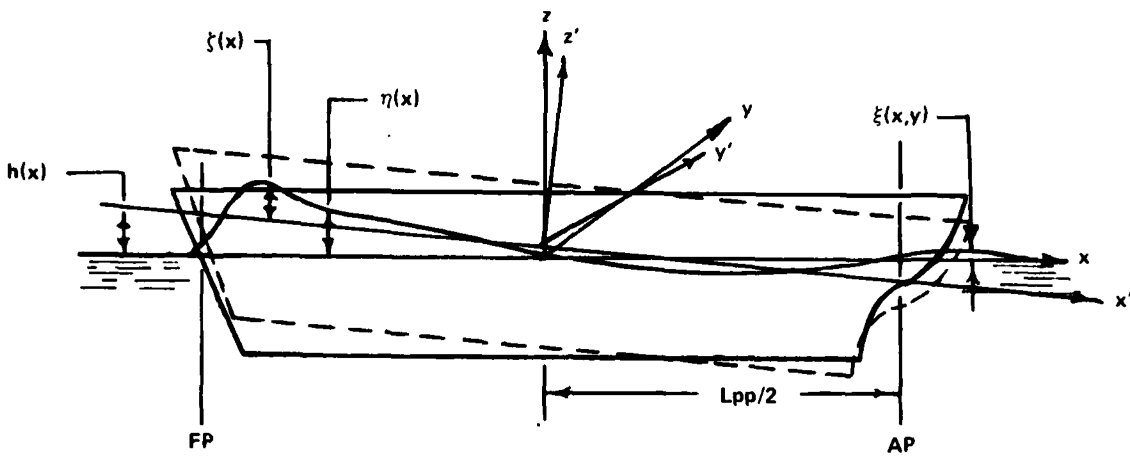
*Nomenclature of Reference 1 is adopted here

K_p	Partial form factor
L	Length at water line
Lpp	Length between perpendiculars
ℓ	Half length, $\ell = L_{pp}/2$
R	Resistance (with subscripts: F for frictional R for residuary, T for total, W for wavemaking and WP for wave pattern)
R_n	Reynolds number, $R_n = UL/\nu$
S	Wetted surface area while underway, due to sinkage and trim only
S_O	Wetted surface area at rest
U	Ship or model speed
V	Displaced volume
WL	Water line
α	Coefficient used with Partial Form Factor K_p, to account for different types of sterns
$\zeta(x)$	Wave elevation along hull, measured relative to the x' - y' plane; nondimensionalized by $U^2/2g$ (See Coordinate System Definition Sketch)
$\xi(x,y)$	Wave elevation, relative to x-y plane, nondimensionalized by $U^2/2g$
$\eta(x)$	Wave elevation along hull, measured relative to the undisturbed free surface plane, nondimensionalized by $U^2/2g$, $\eta(x) = -(h(x) + \zeta(x))$
λ	Wavelength, $\lambda = 2\pi U^2/g$
ν	Kinematic viscosity, $\nu = 1.0018 \times 10^{-5}$ ft^2/s (9.3070×10^{-7} m^2/s) at T = 74°F (23°C), (fresh water)
ρ	Mass density, $\rho = 1.9352$ slugs/ft^3(997.3634 kg/m^3) at T = 74°(23°C) (fresh water)

COORDINATE SYSTEM



x,y,z	Translating coordinate system with x in the opposite direction of the ships's forward motion, z vertically upward, and the origin at the intersection of the planes of the undisturbed free-surface and the midship section.
x',y',z'	Coordinate system fixed in ship and coinciding with the x-y-z system when ship is at rest.

ABSTRACT

Towing tank experiments were conducted on a 1/8.25-scale model of the high-speed transom stern ship, R/V ATHENA, in order to provide data for comparison and evaluation of various analytical predictions. Measurements of total resistance, wave pattern resistance, bow and stern sinkage, and wave heights along and behind the hull were made over a Froude number range of 0.28 to 1.00 with the model free to sink and trim, and captive at zero trim and sinkage. These measurements are compared with an analytical prediction and with measurements made on a 1/14.67-scale model. The wave pattern resistance coefficients of the two scale models agree well between Froude numbers of 0.28 and 0.65. The analytically predicted wave resistance values exceed the measured wave pattern resistance values. The residuary resistance coefficients of the large model are similar in trend to those of the small model for $F_n > 0.35$, and are less than the predicted analytical values throughout the speed range. The presence of a stern wedge on the large model results in less sinkage and trim and slightly smaller values of residuary resistance at Froude numbers above 0.35, when compared to the analytical results and the experimental results of the small model. The reported measurements provide a basis for evaluation of future analytical computations of resistance characteristics for high-speed transom stern ships.

ADMINISTRATIVE INFORMATION

This work has been performed for the General Hydromechanics Research Program (GHR) sponsored by the Naval Sea Systems Command (NAVSEA 05R) and administered by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), under Program Element 61153N, Project SR02301, Task Area SR0230101 and Work Unit 1522-650.

INTRODUCTION

In 1979, DTNSRDC sponsored the first Workshop on Ship Wave-Resistance Computations.[1*] For this workshop, participants were requested to present results of their analytical computations for any of five hull forms of resistance and associated flow characteristics such as sinkage and trim, wave elevations, and pressure distributions wherever applicable to their method. The five hull forms selected for computations were: Wigley parabolic hull, Inui Hull S-201, Series 60, HSVA Tanker and the R/V ATHENA. The first three hull forms were chosen because of the extensive amount of experimental, theoretical and numerical

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*A complete listing of references is given on page 17.

evaluations of wavemaking and viscous resistance available for these hulls. The HSVA Tanker and the R/V ATHENA represent extreme hull forms: the tanker's hull has a high value of block coefficient and a low range of operating Froude numbers; the ATHENA, a naval ship has a transom stern and high values of operating Froude numbers.

In order to increase the limited model data base for the R/V ATHENA in the bare hull condition, resistance experiments were carried out at DTNSRDC and preliminary results were provided to the workshop. This report documents all of the experimental results and compares these final results to the analytical predictions of Dawson[1] and the experimental results of Gadd and Russell.[2]

Because the analytical methods compute resistance and wave profiles for models in the captive and free-to-trim-and-sink modes, the model of the R/V ATHENA (Model 5365) was tested in both modes. Measurements on DTNSRDC Model 5365 were made at one draft and included: total resistance, wave pattern resistance, bow and stern sinkage, and wave heights along the length and behind the model. The experiments were carried out over a Froude number range of 0.28 to 1.00. However, stern wave heights were only measured in the captive mode and at one Froude number. The Workshop committee specified five Froude numbers for the R/V ATHENA analytical computation: 0.28, 0.35, 0.41, 0.48 and 0.65. Experimental measurements were obtained with DTNSRDC Model 5365 at these Froude numbers, for both fixed and free conditions.

The experimental results reported by Gadd and Russell[2] were obtained with a model whose length is 3.2 m, compared to 5.7 m in length for DTNSRDC Model 5365. Gadd's measurements were made with the model free to sink and trim, and over a Froude number range of 0.18 to 0.66. They included total resistance, wave pattern resistance, hull wave profiles, and a velocity survey behind the model. The velocity survey measurements were used to compute the viscous resistance.

In this report, comparisons are made of the experimental results obtained at DTNSRDC with those of Dawson, and Gadd and Russell, of total resistance, wave pattern and wave resistance, hull wave profiles, and sinkage and trim. Additionally, a comparison is made of the stern geometry of DTNSRDC Model 5365, Gadd and Russell's model, and the geometry provided in Reference 1.

In addition to the work presented here, the R/V ATHENA ship was used to conduct full-scale measurements of the propeller disk wake and boundary layer characteristics near the stern.[3] These measurements were correlated with towing tank and wind-tunnel measurements performed at DTNSRDC with a fully appended ship model.[3]

DTNSRDC has recently undertaken an in-depth study of the resistance and flow characteristics of transom stern ships, like the R/V ATHENA. One of the early conclusions[4] from this study was that three-dimensional potential-flow calculation schemes like Dawson's are generally satisfactory in comparison with experimental measurements of total resistance, wave resistance, sinkage and trim, wave elevations, and bottom pressures. This study has also shown that small differences in transom stern geometry can have a measurable effect on the resistance and sinkage and trim characteristics of ships like R/V ATHENA. For this reason, a careful comparison of the hull form geometries used in the computations and in the experiments will be made in this report.

ANALYTICAL PREDICTIONS

The analytical results presented herein are those of Dawson (1979).[1] Dawson carries out a potential-flow solution for a body moving in the free surface using a method that employs simple-source densities distributed on both the surface of the ship hull and on a part of the undisturbed free-surface region which surrounds the ship. The boundary conditions satisfied by the solution are the zero normal flow through the hull surface and the free-surface condition linearized in terms of the double-model velocity. Once the source densities are determined, the solution of the velocities and pressures are determined. Integration of the body pressure force in the axial direction yields the wave resistance and integration in the vertical direction yields the force and moment used to compute the bow and stern sinkage. Having panels on the free surface allows one to compute the wave elevations.[1] Dawson also provides an estimate of the residuary resistance coefficient, C_R, using the following formula:

$$C_R = ((1+\alpha K_p)S/S_o - 1)C_F + C_W \tag{1}$$

where α is 1.5 for transom sterns

K_p is the partial form factor

C_F is the frictional-drag coefficient from the 1957 ITTC Ship-Model Correlation line.

C_W is the wavemaking resistance coefficient

To include the case of a transom stern hull, Dawson created a special paneling arrangement for the free surface. Somewhat more densely spaced panels are placed in a patch behind the transom for a distance equal to the half ship length and as wide as the transom.

For the transom stern, two boundary conditions are to be satisfied simultaneously: zero pressure, and velocity tangency at the stern. In 1979 (and prior to 1983 when the XYZFS program was revised) these two boundary conditions could not be exactly satisfied simultaneously.[5] The consequent inaccuracy in the solution of the Laplace equation resulted in errors in the prediction of sinkage and trim, inducing an error in the resistance prediction as well. A systematic investigation of these errors has not been undertaken and, thus, they are not quantifiable at this time.

There is an inherent limit of applicability of the Dawson program at high Froude numbers. With increasing Froude number, the characteristic wavelength of the dominant wave system becomes comparable to the total length of the paneled region of the free surface. Thus, as F_n increases, fewer and fewer wavelengths are contained within the computational region. To illustrate this problem, one can express the wavelength of the transverse waves along the centerline as

$$\lambda = 2\pi U^2/g = 2\pi \; F_n{}^2 L \qquad (2)$$

Thus, the wavelength-to-hull length ratio is

$$\lambda/L = 2\pi \; F_n{}^2 \qquad (3)$$

Based on the above, at $F_n = 0.5$ for example, the dominant wavelength becomes (1.57)(L). Since the paneled region of the free surface extends approximately to

1.5L aft of the bow, only about one wavelength lies within the computational region ($F_n = 0.5$), resulting in an inadequate representation of the complete ship wave system. This influences the calculation of the (pressure-) resistance of the ship due to the free-surface wave system. No systematic investigation of this effect has been carried out; one may only state that the computational results above $F_n = 0.5$ should be considered inaccurate.

For the ATHENA model (Model 5365), Dawson digitized the hull form using the body-plan provided to the Workshop participants. This body plan included stations 18, 19, 19-1/2 and 20, and did include the stern wedge. Due to computer memory limitations, Dawson defined the hull with only 25 stations and nine points per station. The total number of panels distributed on the hull and the free surface was limited to 560 panels in 1979. There has been no systematic investigation of the effect of the number of panels used on the accuracy of the computed results. It is expected, however, that the effect of the number of panels used (above 560) on the results is less than the effect of not exactly satisfying the stern boundary conditions mentioned above.

Dawson's predictions of wave resistance, estimated residuary resistance, sinkage, trim, and wave profiles along the hull are shown in figures along with the experimental results.

DESCRIPTION OF EXPERIMENTAL CONDITIONS

TEST FACILITY

The experiments were conducted at DTNSRDC on Carriage One, in the main towing basin, which is approximately 840 ft (256 m) long and 50.9 ft (15.5 m) wide. Resistance measurements were taken in a constant water depth of 22 ft (7 m). Wave dampers are located along the two sides of the towing tank to reduce the amount of wave energy that is reflected back toward the center of the towing tank.[6]

The model was attached to the floating girder on Carriage One. The carriage is powered with hydraulic motors and has a speed range of 0.5 to 18.0 knots. Carriage speed is measured using a gear and magnetic pick-up mounted on one of the carriage wheels. During the experiments, the temperature of the water in the towing tank at a depth equal to the draft of Model 5365 was 74°F (23°C).

SHIP MODEL

Model 5365 represents the R/V ATHENA, a high-speed, transom stern displacement ship. Model 5365 was built of fiberglass using a mold of a wooden model of the R/V ATHENA, Model 4950-1, to a scale ratio, $\lambda = 8.25$. Figures 1 through 3 present an abbreviated lines plan of the R/V ATHENA, a fore-body plan (stations 0 to 10) and an after-body plan (stations 10 to 20). Hull form parameters and principal dimensions of Model 5365 are presented in Table 1.

Offsets of the hull form are shown in nondimensional form in Table 2.[1] Table 3 compares the stern geometry of R/V ATHENA as presented in References 1 and 2, and on drawings at DTNSRDC. Figure 4 shows the stern profiles of two DTNSRDC hull forms (one without a stern wedge and one with a stern wedge) and Gadd and Russell's model as described in Reference 2. The profile heights are nondimensionalized by draft so that a comparison can be made between the two models of different size. The stern profiles are compared on the centerplane ($y/B_{max} = 0.0$) and at the 0.50 buttock ($y/B_{max} = 0.25$). Both the ship, R/V ATHENA, and Model 5365 have the integral stern wedge.

As shown in Figure 4, the profiles with the stern wedge have a definite hook in them from station 19-1/2 to station 20. The stern profiles of Gadd and Russell's model were drawn from the data provided in Reference 2, Appendix 1 (Gadd and Russell). As shown in Figure 4, the heights above the baseline at station 20 of Gadd and Russell's model agree better with the "no wedge" geometry than with the tested "with wedge" geometry of DTNSRDC. The difference in the stern geometry between DTNSRDC Model 5365 and the NMI model (Reference 2) is due to model manufacturing errors.*

It is concluded that Gadd and Russell's model does not have a stern wedge. The effect of this difference in stern geometry on the experimental results are discussed later in this report.

Offsets of the hull forms at stations 18, 19, 19-1/2, and 20 are also presented in Table 3. In general, from the limited amount of geometric data, the agreement is good between the offsets of the DTNSRDC (w/wedge) drawing, and those of References 1 and 2. In order for the wedge to be adequately defined with offsets only, Reference 1 should have included more offsets between the waterlines of 0.50 and 0.75.

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*Private communication with Dr. G.E. Gadd of National Maritime Institute.

Model 5365 was tested in the bare hull condition, with the centerline skeg in place. A turbulence stimulating tripwire of 0.024 inch (0.61 mm) diameter was attached to the hull, parallel to the stem, at 1/20th of the hull length aft of the forward perpendicular. The surface of the model was unpainted and appeared to be hydraulically smooth, although the surface roughness was not measured.

Model experiments were conducted in the free to sink and trim mode, and in the captive mode. Two methods were used to attach the model to the carriage. For the free to sink and trim mode, a towing bracket was attached to the model on its centerplane at station 4-1/2 and the vertical location of the attachment point was at the waterline, with the model at rest. Another bracket was attached to the model at station 19-1/2. These two brackets only allowed the model to pitch, heave, and roll. For the experiments in the captive mode, two ogival-shaped struts were attached to the inside of the model on the centerplane, one at station 8 and the other at station 16.

The model was tested at an even keel draft of 0.60 ft (0.18 m), representing a full-scale displacement of 214 long tons (210 t).

MEASURING EQUIPMENT

Total resistance of the model was measured with the floating girder that is attached to the carriage.[6] Wave pattern resistance was determined from measurements of the height of the waves generated by the passing ship model (longitudinal wave-cut). The wave heights were measured with one parallel wire resistance type transducer, mounted on a boom extended from the side of the towing tank toward the center. The boom is mounted at mid-length of the towing tank. Thus, the ship model reaches steady state speed and has a fully developed wave system before it passes the wave height probe.

The bow and stern sinkage of the model were measured with two displacement transducers that were mounted at the bow and stern of the model.

The wave elevation along the side of the model was recorded manually, using a grease pencil to mark the water height at 25 locations. Subsequently, the distance between the marked heights and the calm water surface was measured, taking into account the sinkage and trim of the model.

The stern wave heights were obtained using thin rods that were manually adjusted until their tips just touched the water surface, once the model reached a steady state condition.

COMPUTER EQUIPMENT

Two Model 70 Interdata mini-computers were used for data collection and reduction. One computer located on the towing carriage was used to collect resistance, speed, and bow and stern sinkage data. Another computer was located along the side of the towing tank for collection of the wave height data and computation of the wave-pattern resistance. For both computers, a data collection rate of 100 samples per second was used. The speed and sinkage data were averaged over a 5-s time period for a data point. The resistance of the model was determined from strip chart records of the floating girder data over a 10- to 20-s time period while the model speed was constant, and then manually typed into the computer for each data spot.

MEASUREMENT ACCURACY

The measured total resistance of the model was found to be repeatable within $\pm 1.5\%$ of the measured value, corresponding to a random error in C_R of $\pm 0.06 < C_R \times 10^3 < \pm 0.08$ over the Froude number range of the current experiments. This is consistent with historical data for surface-ship models at DTNSRDC.

There are two bias-errors included in the resistance data presented in this report. One is associated with the drag of the tripwire used to stimulate turbulence on the model hull; the other is the error introduced in the total resistance measurements due to the air-drag of the model towing apparatus.

For normal ship-resistance prediction work, it is customary at DTNSRDC to neglect the effect of both tripwire and air-drag on the measured surface ship model resistance results. This is to conform with both historical model data at DTNSRDC and to be consistent with the model-ship correlation allowance derived from model and ship trial data for various naval combatants.

In order to be consistent with the model historical data base of DTNSRDC, and with previously published data on the ATHENA (i.e., Reference 1), the model-resistance data presented in this report is not corrected for the drag of the tripwire and the air drag. The bias error introduced in the model resistance data for the ATHENA model is shown in Figure 5. The net model resistance can be computed readily, with the use of this figure. For example, using the average values of C_3 from the figure, the net model residuary resistance may be computed as (free to sink and trim condition):

$$C_{R_{net}} \cong (C_3)\ C_R = (0.976)\ C_R$$

where C_R is the residuary resistance data presented in this report for the ATHENA model (Model 5365); and similarly for the captured mode:

$$C_{R_{net}} \cong (0.972)\ C_R$$

The air resistance of the floating girder and the towing apparatus, used in Figure 5 was computed from experimental data obtained for Reference 4. The tripwire drag used in Figure 5 was computed with the use of Reference 7. As seen in the figure, the error due to the tripwire is less than +0.5 percent of the measured resistance, and neglecting the air-drag introduces an error of less than +2.5% over the F_n range.

The accuracy of the wave pattern resistance coefficient, C_{WP}, calculated from wave-height measurements of the model's wave train, is affected by the calibration of the wave height probe and the repeatability of the height measurements. From References 8 and 9, the wave pattern resistance coefficient is proportional to the square of the wave height. The ratio of the wave height probe calibration factors squared would be the change in the wave pattern resistance coefficient. From the data available at this time, the accuracy of the wave pattern resistance coefficients, C_{WP}, were found to be $\pm 6\%$.

Experiments are planned in the future to quantify all the sources of error in the longitudinal wave-cut method and in the computation of the wave pattern resistance coefficients.

The bow and stern sinkage coefficients, C_{sf} and C_{sa} were repeatable within ± 0.001. The wave profile measurements on the hull and the wave height measurements behind the transom were repeatable within ± 0.5 inches (± 12.7 mm), which corresponds to $\eta(x)$ (nondimensional wave profile height) and $\xi(x,y)$ (nondimensional stern-wave height) of ± 0.06 and ± 0.004 at Froude numbers of 0.28 and 1.00, respectively.

RESULTS

RESISTANCE

Figure 5 and Table 4 present the total, residuary and wave pattern resistance coefficients for Model 5365 free to sink and trim as a function of length Froude number. Included in Figure 5 are the analytical results of Dawson[1] and the experimental results of Gadd and Russell[2]. Note that the resistance coefficients are nondimensionalized using the static (at rest) wetted surface, S_o of the model. The experimental values of C_R were computed using the 1957 ITTC Ship-Model Correlation Line for the frictional resistance coefficient. As discussed earlier, the parasitic drag of the tripwire on Model 5365 was neglected.

The wave pattern resistance for Model 5365 was computed using the longitudinal wave-cut method of Sharma[8] and a series of computer programs documented by Reed.[9] One can see in Figure 6 that the experimental values of C_{WP} from the two sets of experiments agree fairly well over the Froude number range of 0.28 to 0.65. These results do not appear to be affected by the differences in stern geometry. The analytical results of C_W by Dawson are greater than the experimental values of C_{WP} at all speeds and by as much as 2.3×10^{-3} higher at the lower speeds. The difference decreases as Froude number increases up to a value of $F_n = 0.48$, after which the difference increases again. The analytical results of C_R compare better with the experimental values of C_R than the analytical values of C_W compare with the experimental values of C_{WP}. The agreement of C_R between the current results (DTNSRDC) and those of Gadd and Russell is fairly good for $F_n > 0.35$. At $F_n > 0.48$, the current results of C_R are lower than those of Gadd and Russell's, and this trend is probably due to the differences in stern geometry which result in less sinkage for Model 5365. Below $F_n = 0.35$, the values of C_R for the small model fall off whereas the values from the larger model increase with decreasing Froude number. Except at $F_n = 0.48$, where

Dawson's and Gadd and Russell's results agree, both sets of experimental C_R values are lower than Dawson's analytical results.

Figure 7 and Table 5 present the resistance data for Model 5365 fixed at zero trim and sinkage (captive). Figure 6 also includes values of C_W and C_R computed by Dawson for the captive condition. The comparison of C_W to C_{WP} shows the same trend as in the free to sink and trim case. Namely, the analytical values of C_W are larger than the experimental values of C_{WP}. The analytical values of C_R are greater than the experimental values up to a Froude number of 0.48. Above $F_n = 0.48$, the experimental values of C_R are greater than those computed by Dawson.

Figures 8 through 14 show stern view and profile view photographs of Model 5365 at various Froude numbers, in the free and captive modes of sinkage and trim. Figures 8 and 9 show the stern of the model (free trim and captive, respectively) at $F_n = 0.28$. At this speed, in both trim conditions, the flow has just separated. Clean breakaway of the flow from the transom occurs above $F_n = 0.28$, as shown in Figures 10 and 11. With the flow separated from the transom, the resistance coefficients, C_T and C_R for the current experiments drop off between $F_n = 0.28$ and 0.35, as shown in Figures 6 and 7. Figure 12 is a profile view of Model 5365 free to sink and trim at $F_n = 0.48$, where bow wave breaking was first observed. Figures 6 and 7 show that above $F_n = 0.48$, the wave pattern resistance coefficient decreases. The amount of wave breaking increases substantially at high speeds, as shown in Figure 13 and 14. At $F_n = 1.00$ there is a large amount of spray.

Figure 15 compares the differences in the measured C_T and C_{WP} between the captive condition and the free to trim and sink case for Model 5365. It appears that the wave pattern resistance does not account for all of the difference in the total resistance between the two conditions at $F_n < 0.80$. Above $F_n = 0.80$, the differences in C_T and in C_{WP} due to sinkage and trim, are approximately the same, and these values are small.

SINKAGE AND TRIM

The measured bow and stern sinkage of Model 5365 are compared to the results of Dawson and those of Gadd and Russell in Figure 16. The bow and stern sinkage are nondimensionalized by ℓ, half of the hull length. The sinkage at midships as a function of Froude number for all three sets of results is shown in Figure 17. Figure 18 shows the trim coefficient as a function of Froude number. Table 6 presents the measured bow and stern sinkage for Model 5365, along with the calculated midship sinkage and trim in nondimensional form. From Figure 16 one can see that below a Froude number of 0.48 the two sets of experimental results are in better agreement with each other than with Dawson's results, and the greatest differences between Dawson's values and the experimental results are at the bow. However, at the higher Froude numbers, the current results show less trim than both Dawson's and Gadd and Russell's results at both the bow and at the stern. Figure 17 shows that Dawson's values of midship sinkage at $F_n = 0.48$, 0.57, and 0.65 change very little.

Both sets of experimental results show a reduction in the midship sinkage at the higher Froude numbers, to the point where, at $F_n = 1.00$, the current results show that the underway draft of the model is less than the draft of the model when it is at rest. The variation in trim coefficient with Froude number (Figure 18) shows that Dawson's values are larger than both sets of experimental results for $F_n < 0.57$. At $Fn = 0.57$ and 0.65, Gadd and Russell's trim coefficients are in better agreement with Dawson's predictions than the current measurements.

WAVE PROFILES

Table 7 presents the nondimensional wave profile heights along the hull for Model 5365 in the free to sink and trim condition. The measured wave heights are nondimensionalized by $U^2/2g$, (η), and are referenced to the calm water free surface. Figures 19, 20, and 21 present the nondimensional wave profile heights along the hull for Model 5365 in the free to sink and trim mode at $F_n = 0.28$, 0.35, 0.41, 0.48 and 0.65. Results from Dawson and Gadd and Russell are also shown in these figures, where appropriate. At the five Froude numbers, the agreement between the two experiments is better on the forebody than on the afterbody. Aft of midships, there are shallower troughs for the current results than for those of Gadd and Russell. The wave profile heights computed by Dawson at $F_n = 0.35$, 0.41, and 0.48 are in good agreement with the measurements of Gadd and Russell aft of midships. On the bow quarter ($-1.0<x/\ell<-0.5$), Dawson's predicted wave elevations are less than both sets of experimental data. His results also show a kink in the wave profile on the fore body which was not observed in either experimental investigation.

Table 8 presents the nondimensional wave-profile heights for Model 5365 in the fixed zero trim and sinkage condition at F_n = 0.28, 0.35, 0.41, 0.48 and 0.65. Figures 22, 23 and 24 show these results along with those computed by Dawson at F_n = 0.35, 0.41 and 0.48. There is better agreement between the two along the forebody than in the free trim case. On the afterbody, the experimental results have shallower troughs than the analytical results, similar to the free to sink and trim case. In general, the agreement between the current experimental results and Dawson's values for the captive trim condition is better than in the free trim case.

STERN WAVE ELEVATIONS

Measurements of the stern wave elevations were made on Model 5365 in the captive mode at a Froude number of 0.48. The measured values are nondimensionalized by $U^2/2g$, $\xi(x,y)$ and presented in Table 9. The measurement grid x/ℓ and y/ℓ represent distances aft of the transom (x/ℓ=1.0) and distances outboard of the longitudinal centerplane (y/ℓ =0.0). The stern wave elevations are plotted in transverse planes in Figures 25, 26, and 27, and in longitudinal planes in Figures 28 and 29. In Figures 25, 26, and 27, the outline of the transom (station 20, x/ℓ=1.0) is shown. Figures 28 and 29 present the profile of the model at the corresponding value of y/ℓ. There are no comparisons with Dawson's calculations of stern-wave elevations because the panels on the free surface aft of the transom in Dawson's program were larger than the region of experimental measurements. However, these stern wave elevations can be used for future comparisons.

DISCUSSION

The agreement in the wave-pattern resistance coefficients for the R/V ATHENA (free to trim) is good between the current experimental measurements and those of Gadd and Russell. Both sets of results were obtained using the longitudinal wave-cut method, but employed different analysis schemes and a different number of wave-height probes. The differences in the stern geometry between the two models do not appear to have an effect on the longitudinal wave-cut data presented here. In comparison, the analytical prediction by Dawson (1979) showed values of wave-resistance coefficient much larger than experimental values over the entire Froude number range for the free to trim case. Furthermore, at $F_n < 0.35$, the trend in C_W does not agree with the trend in C_{WP} from the experiments, but rather with the trend in C_R measured with the large model.

The two sets of experimental values of residuary resistance coefficient for the free to trim and sink case agree well for $F_n > 0.31$. Below $F_n = 0.31$, the values of C_R for the small model fall off, whereas the value of C_R for the large model at $F_n = 0.28$ is greater than the value at $F_n = 0.31$. As suggested by Gadd and Russell, the difference in C_R between the two experiments at low Froude numbers may be due to a Reynolds number effect on the base pressure drag.[2] The analytical values of C_R agree better with the values from the large model at values of Froude number less than 0.35. Above $F_n = 0.35$, Dawson's values are similar to both sets of experimental values, but slightly higher. The relative magnitudes of C_R among the three sets of data at $F_n > 0.48$ may be due to the differences in sinkage and trim resulting from the different stern conditions.

The difference in the resistance between the two trim conditions is significant, particularly in the range of Froude numbers from 0.35 to 0.80. As suggested by Chang,[1] the difference in resistance between the free and fixed zero trim conditions at speeds above breakaway ($F_n > 0.28$) may be due to the hydrostatic component of resistance caused by the large immersed transom when the model is sunk and trimmed. At $F_n > 0.80$, where sinkage and trim are negligible, there is only a small amount of hydrostatic resistance, and the differences in C_R and C_{WP} due to sinkage and trim are small. Hence, for the R/V ATHENA, Chang's suggestion that hydrostatic drag is important seems reasonable. After the occurrence of flow breakaway ($F_n > 0.28$), the resistance drops off until the hydrostatic resistance becomes dominant (stern sinkage) and the resistance starts increasing again.

Above $F_n = 0.48$, wave breaking and spray generation increase with increasing F_n. In this high F_n range, the values of C_{WP} drop off at a faster rate than do the C_R values, as F_n increases. It appears that wavebreaking and spray add resistance to the ship, and this resistance increase is not reflected in the measured-wave-pattern resistance obtained with the longitudinal wave-cut method.

The sinkage and trim from the three sets of results show the importance of stern geometry on high speed displacement ships. Model 5365 was built from a complete set of lines and actually has a wedge on the stern, whereas the calculations by Dawson were carried out for the hull form defined by only 9 offset points at 25 longitudinal positions (Reference 1). The model tested by Gadd and Russell did not have a stern wedge on it due to model manufacturing errors. As shown in Reference 10, the presence of a stern wedge results in less resistance and smaller trim angles. The stern wedge creates lift on the transom and, thus, reduces the trim. The results of Gadd and Russell show that without a wedge the trim will be greater than if a stern wedge were present. Dawson's prediction of sinkage and trim and resistance would probably correlate better with experimental results if the stern boundary conditions were satisfied exactly, and if the panel sizes near the stern of the ship and immediately behind the transom on the free surface, were reduced.

Since 1979, work has continued on improving the numerical computation of resistance for transom stern ships. One of the improvements has been to change to a computer with a larger memory so that now 28 stations are specified and the total number of panels has increased from 560 to 784.[5]

For the free to sink and trim case, the wave profiles on the fore body for the two experimental results are in better agreement than those on the after body because the bow trims (Figure 15) of the two models are in better agreement than the stern trims. Similarily, Dawson's predictions of fore-body wave profiles at Froude numbers below 0.57 are less than the experimental results because the predicted bow rise is larger than both sets of experimental results. On the after body, the current results differ from both of the other two, and they (Dawson and Gadd and Russell) agree quite well at F_n = 0.35, 0.41, and 0.48. The agreement between Dawson's calculated wave profiles and those measured on the small model are due to the similarity in stern sinkage. At the transom ($0.9 \leq x/\ell \leq 1.0$), Dawson's results diverge from those of Gadd and Russell probably because the stern boundary conditions are not satisfied exactly.

The wave profile heights for Model 5365 were obtained by marking the wave height on the model with a grease pencil while the model was towed in the tank at constant speed. As stated in Reference 2, the wave heights on the smaller model were obtained from photographs of the model (which had stations and waterlines painted on it) while it was underway. For the current results, it was found to be difficult to obtain accurate wave profile heights from photographs (see Figures 12, 13 and 14). The two techniques used to obtain wave-profile data may be another source of discrepancy between the two sets of data.

The stern-wave elevations measured on the larger model show that in the captive-trim case, at a Froude number of 0.48, the flow breaks cleanly from the transom along the entire transom width, and the wave elevation just outboard of the transom is equal to calm-water free-surface elevation.

CONCLUSIONS

1. The results presented in this report are in agreement with previous work which shows that stern wedges reduce sinkage and trim. For the R/V ATHENA, these results show that less sinkage and trim is obtained at Froude numbers above 0.35 when a stern wedge is present, than for the ship without a wedge.

2. The wave pattern resistance obtained from longitudinal wave cuts measured for two models of the R/V ATHENA, shows good agreement over the range of Froude numbers from 0.28 to 0.65.

3. Dawson's analytical values of wave resistance for the R/V ATHENA (1979) are larger than the experimental values of wave pattern resistance over the Froude number range of 0.28 to 0.65 for both the free and captive conditions of sinkage and trim.

4. The residuary resistance of the two models is in reasonable agreement at Froude numbers of 0.35 and above. The analytical values of C_R (residuary resistance coefficient) agree better with the experimental results of C_R than the analytical values of C_W agree with the experimental results of C_{WP}.

REFERENCES

1. "Proceedings of the Workshop on Ship Wave-Resistance Computations," Vol. I and II, DTNSRDC, Bethesda, MD (Nov 1979).

2. Gadd, G.E., and M.J. Russell, "Measurements of the Components of Resistance of a Model of R.V. 'ATHENA'," NMI R119, National Maritime Institute (Oct 1981).

3. Day, W.G. et al, "Full-Scale Propeller Disk Wake Survey and Boundary Layer Velocity Profile Measurements on the 154 Foot Ship R/V ATHENA," DTNSRDC Ship Performance Department Report DTNSRDC/SPD-0833-01 (Sep 1980).

4. O'Dea, J. et al, "Flow Characteristics of a Transom Stern Ship," DTNSRDC Report 81/057 (Sep 1981).

5. "Proceedings of Second DTNSRDC Workshop on Ship Wave-Resistance Computations," DTNSRDC, Bethesda, MD (Nov 1983).

6. Vincent, M. daC., "The Navy's Center of Excellence for Ship Research," NSRDC Report 3039 (Nov 1971).

7. Sung, C.H. and D.S. Jenkins, "The Drag of a Circular Cylinder on or Near a Flat Plate Appropriate for Ship-Model Turbulence Stimulators," DTNSRDC Ship Performance Department Report DTNSRDC/SPD-1018-01 (Feb 1983).

8. Sharma, S.D., "An Attempted Application of Wave Analysis Technique to Achieve Bow-Wave Reduction," Sixth ONR Symposium on Naval Hydrodynamics, pp 731-773 (1966).

9. Reed, A.M., "Documentation for a Series of Computer Programs for Analyzing Longitudinal Wave Cuts and Designing Bow Bulbs," Ship Performance Department Report DTNSRDC/SPD-0820-01 (June 1979).

10. Kracht, A and O. Grim, "Widerstand, Propulsion, Bewegung und Beanspruchung schneller Verdrängungsfahrzeurge in glatten Wasser und in regelmäßigem Seegang," Institut Für Schiffbau Der Universitat Hamburg, IFS-Bericht Nr. 167, Hamburg (July 1966).

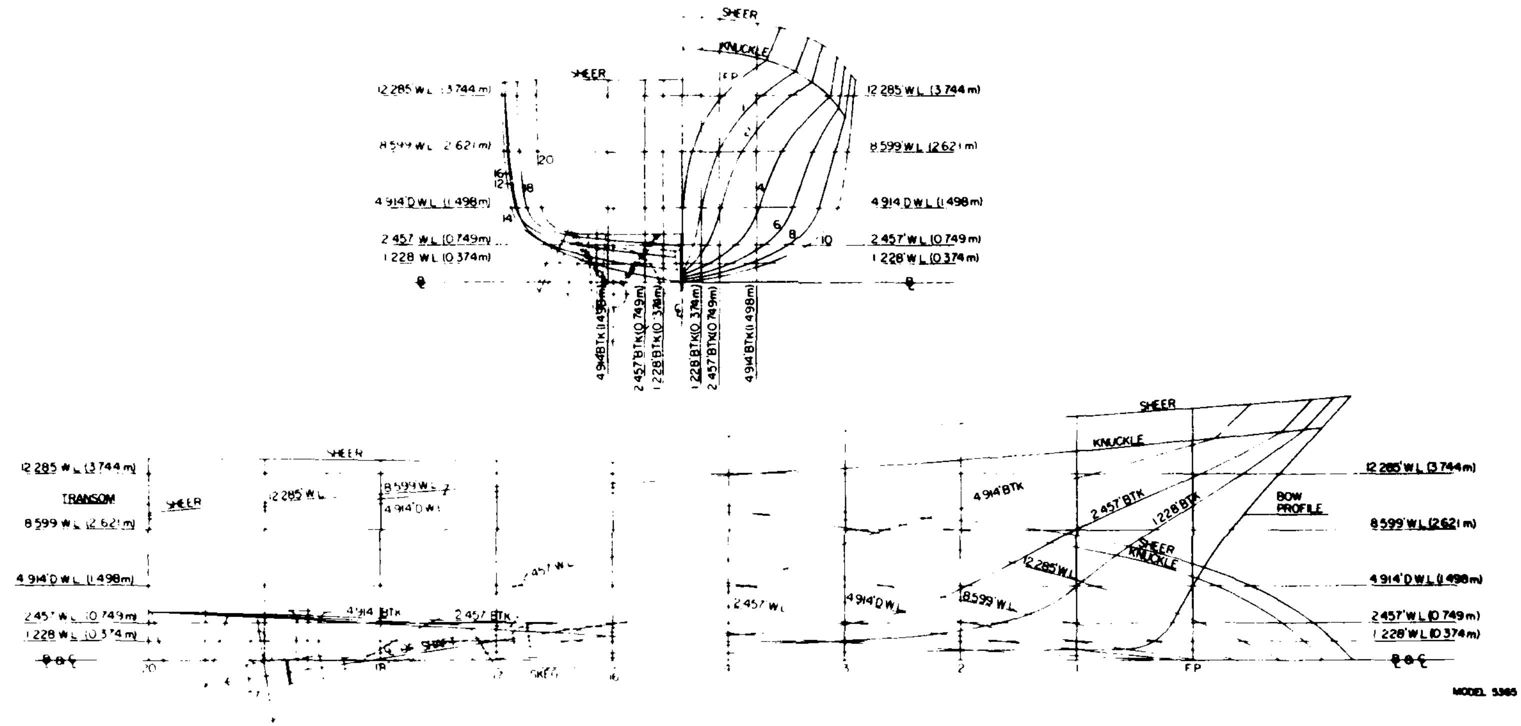


Figure 1 - Abbreviated Lines Plan of R/V ATHENA, Represented by Model 5365

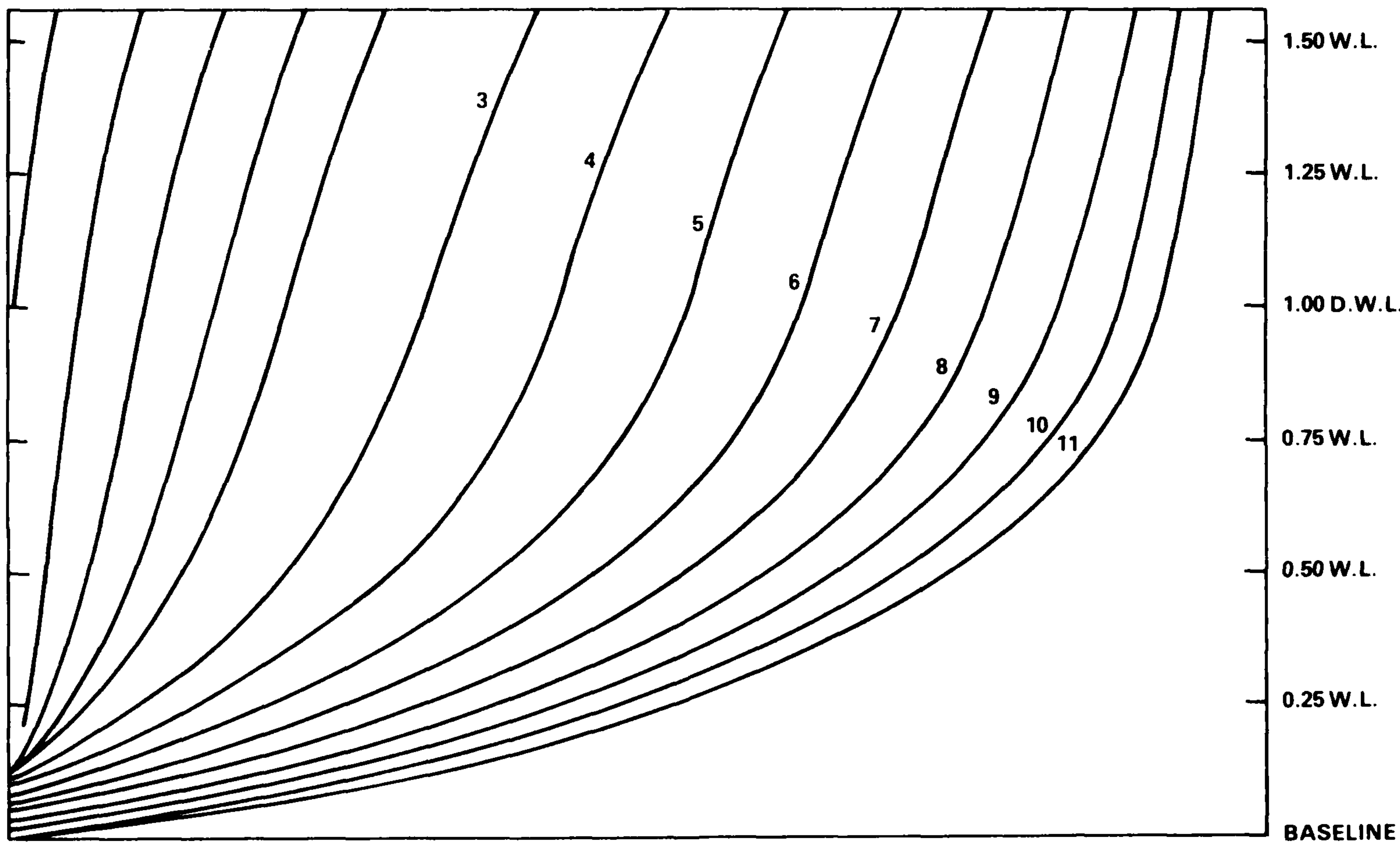


Figure 2 - Body Plan of the Fore Body of R/V ATHENA, Represented by Model 5365

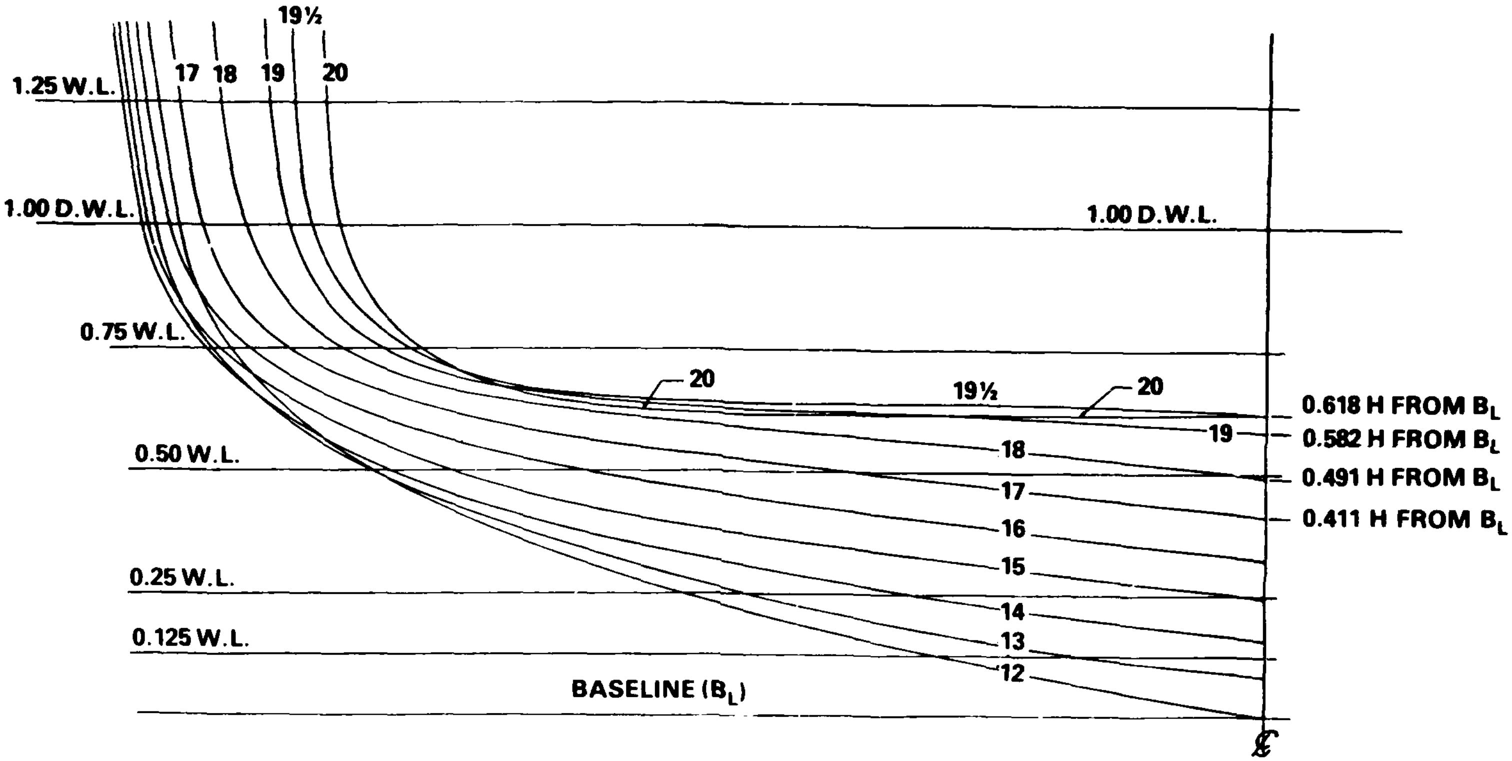


Figure 3 - Body Plan of the After Body of R/V ATHENA, Represented by Model 5365

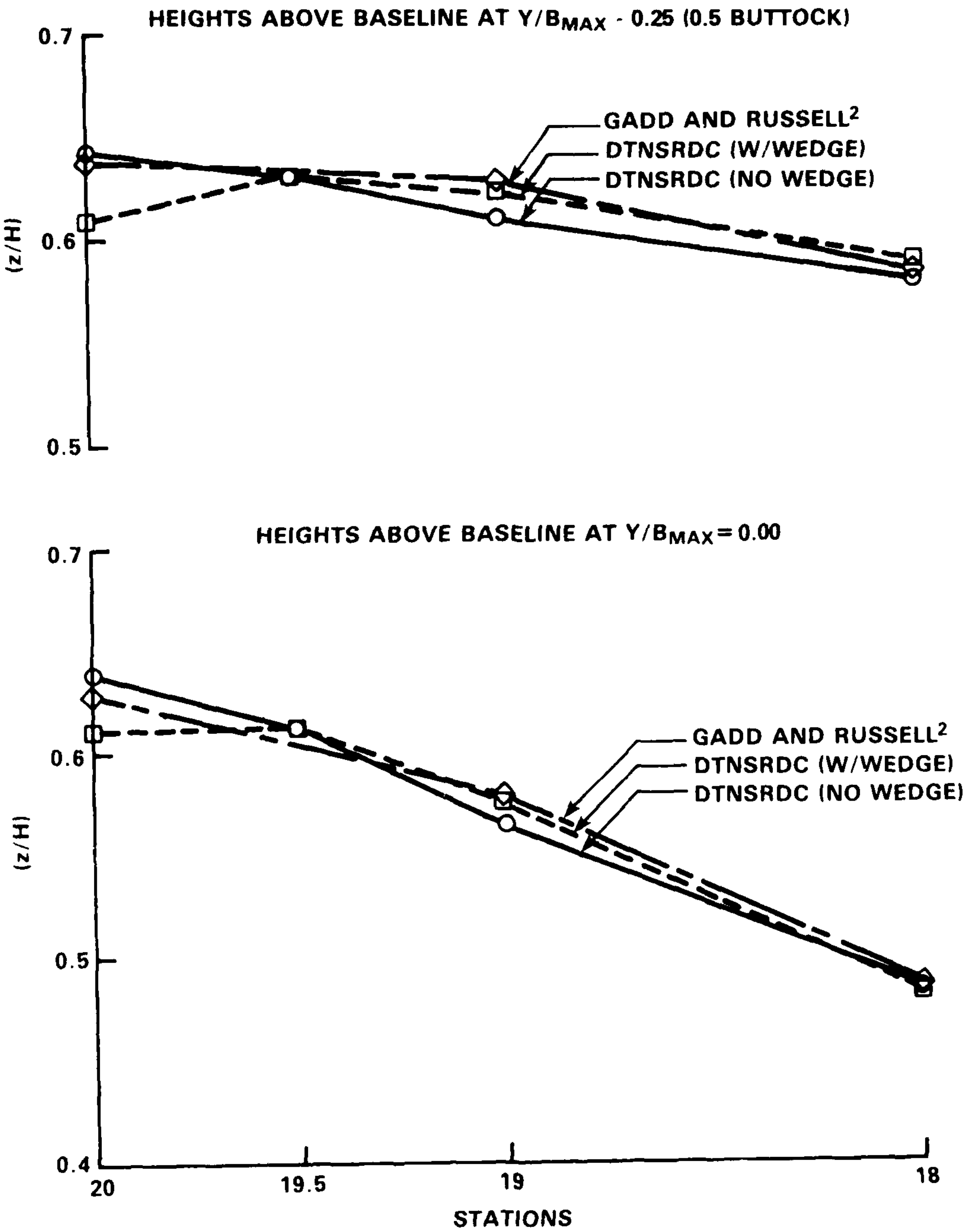


Figure 4 · Comparison of Stern Geometry for R/V ATHENA

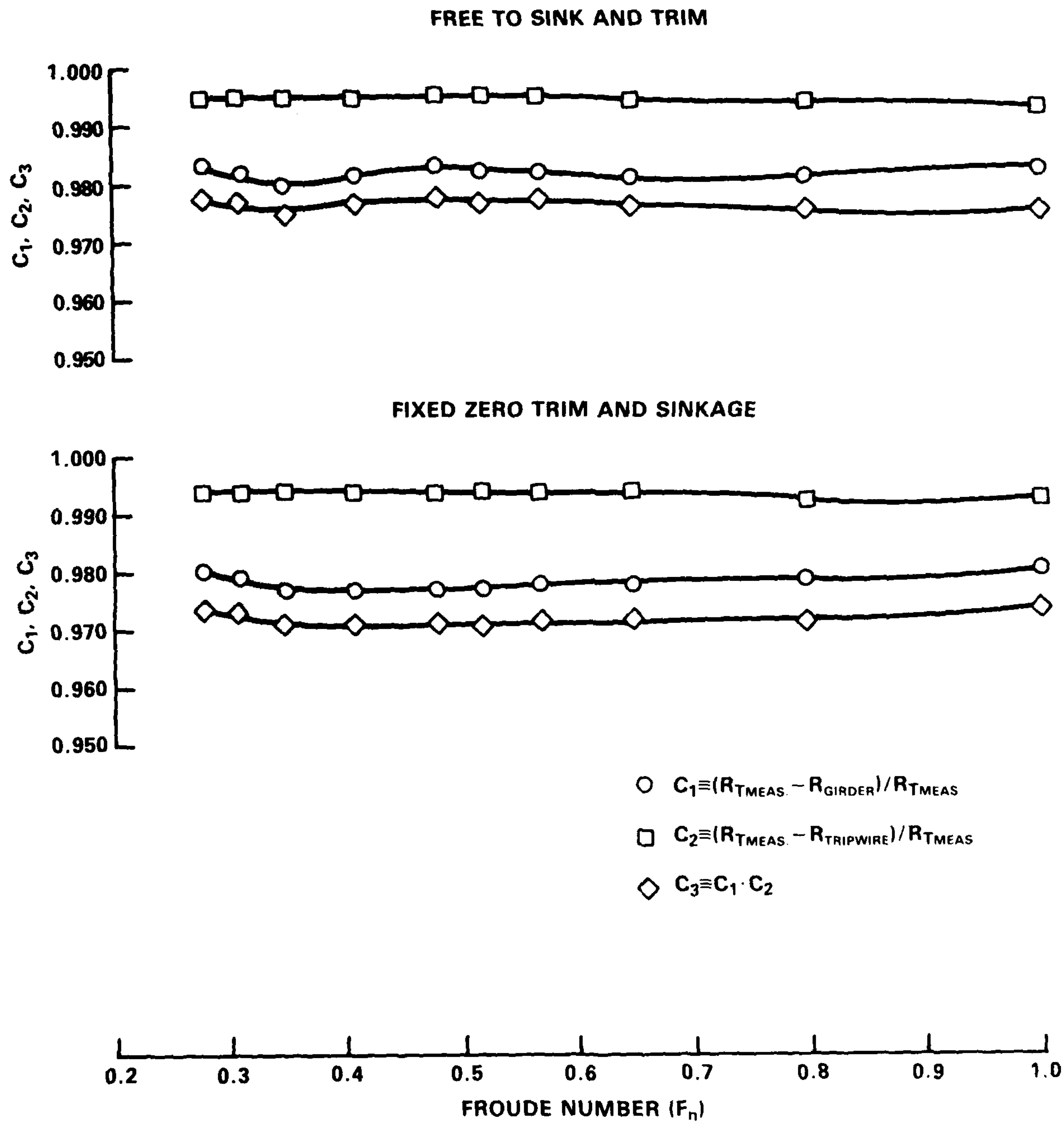


Figure 5 - Model Resistance Correction Factors versus Froude Number for Model 5365

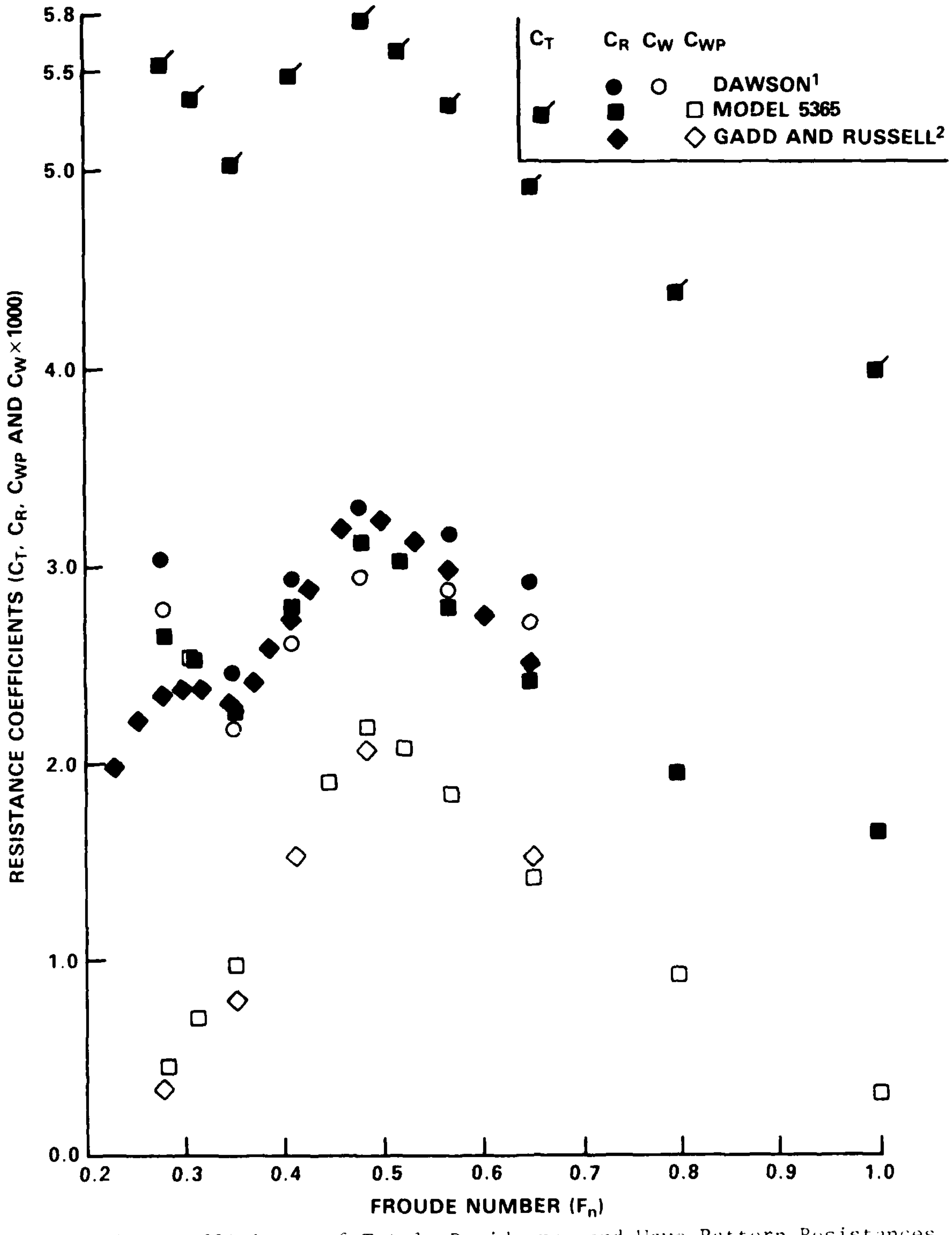


Figure 6 - Coefficients of Total, Residuary, and Wave Pattern Resistances for R/V ATHENA, Free to Sink and Trim, as Determined from Experiments with Model 5365 and Compared to the Results of Dawson and Gadd and Russell

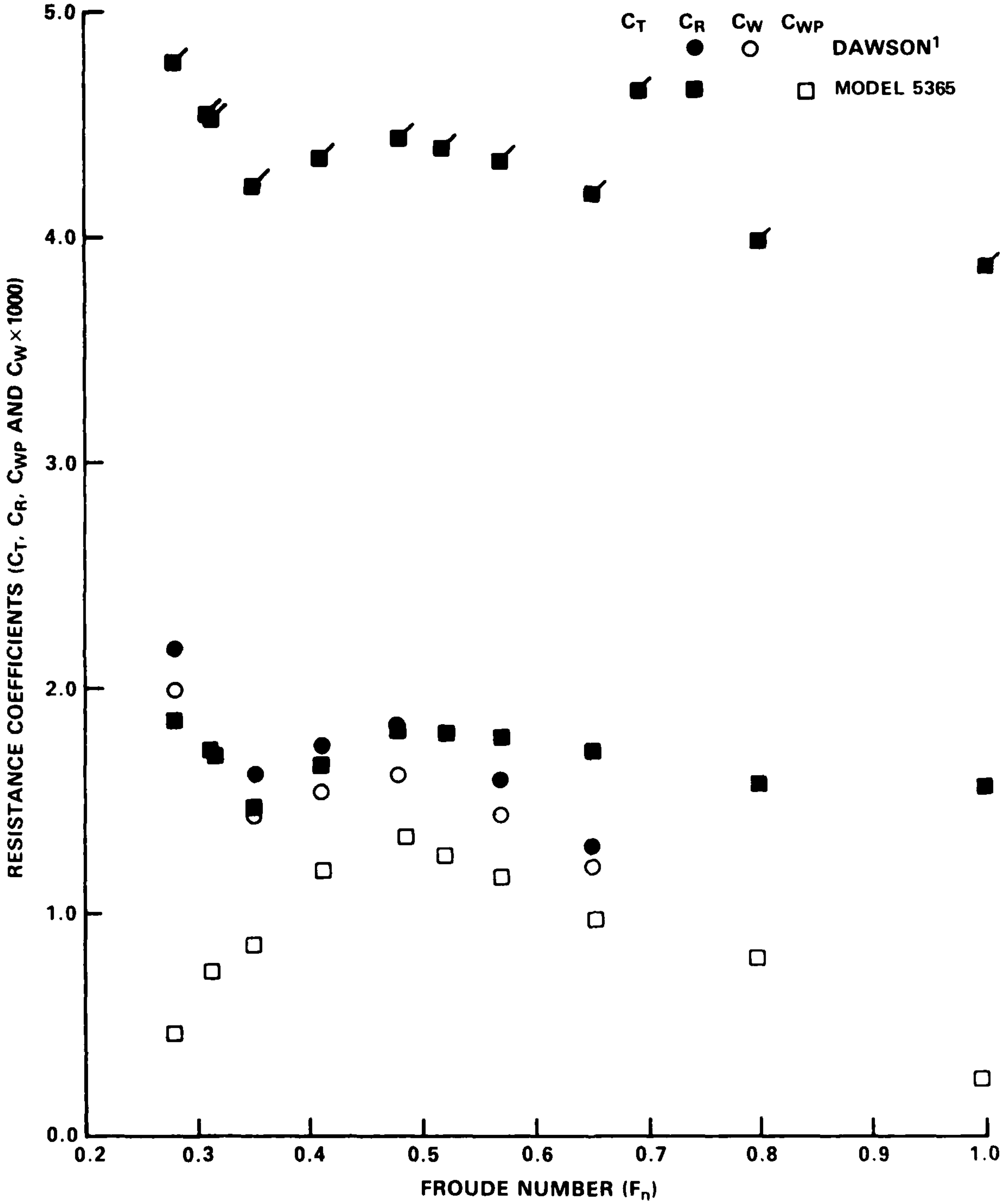


Figure 7 - Coefficients of Total, Residuary, and Wave Pattern Resistances for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments and Compared to the Results of Dawson


5365

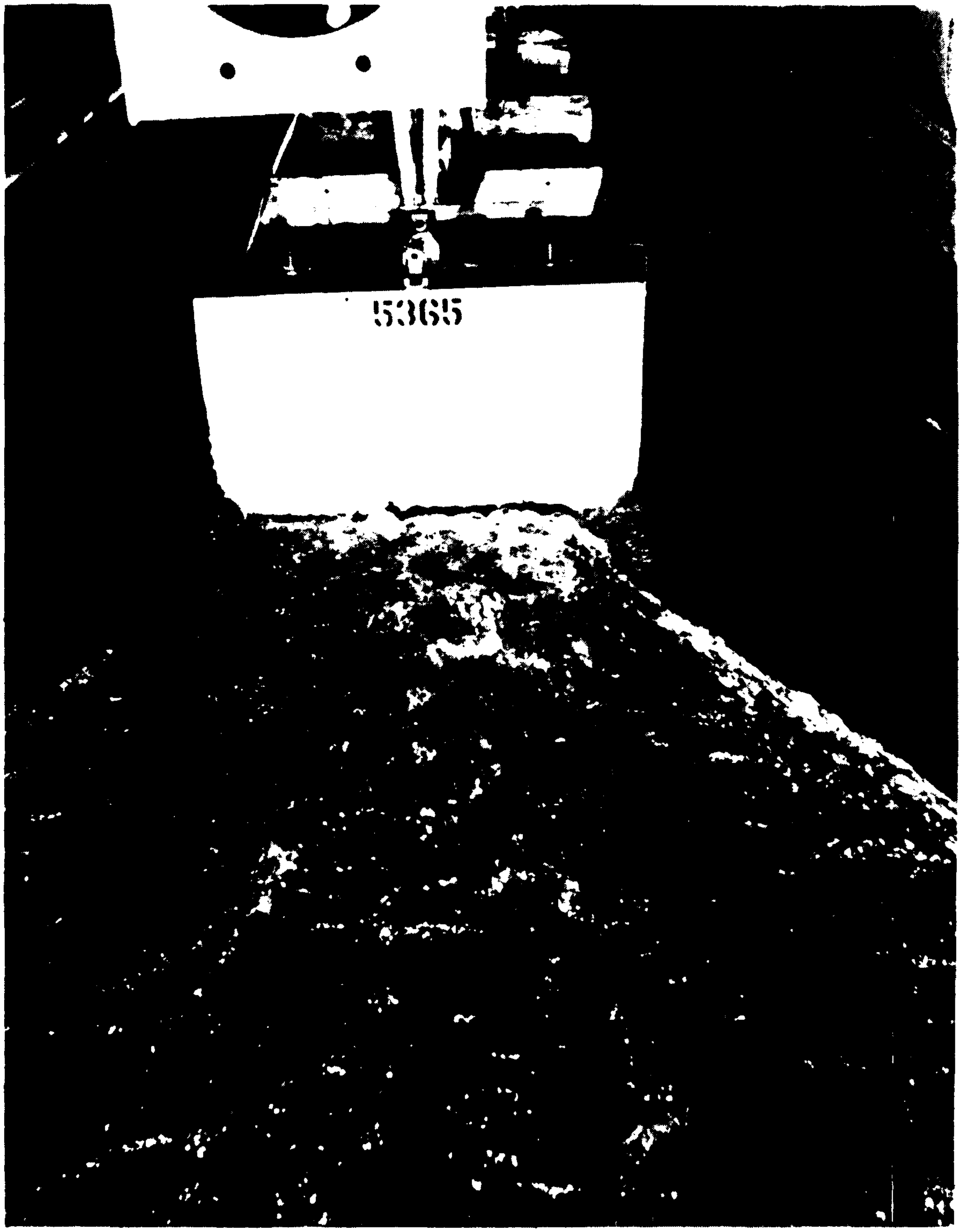
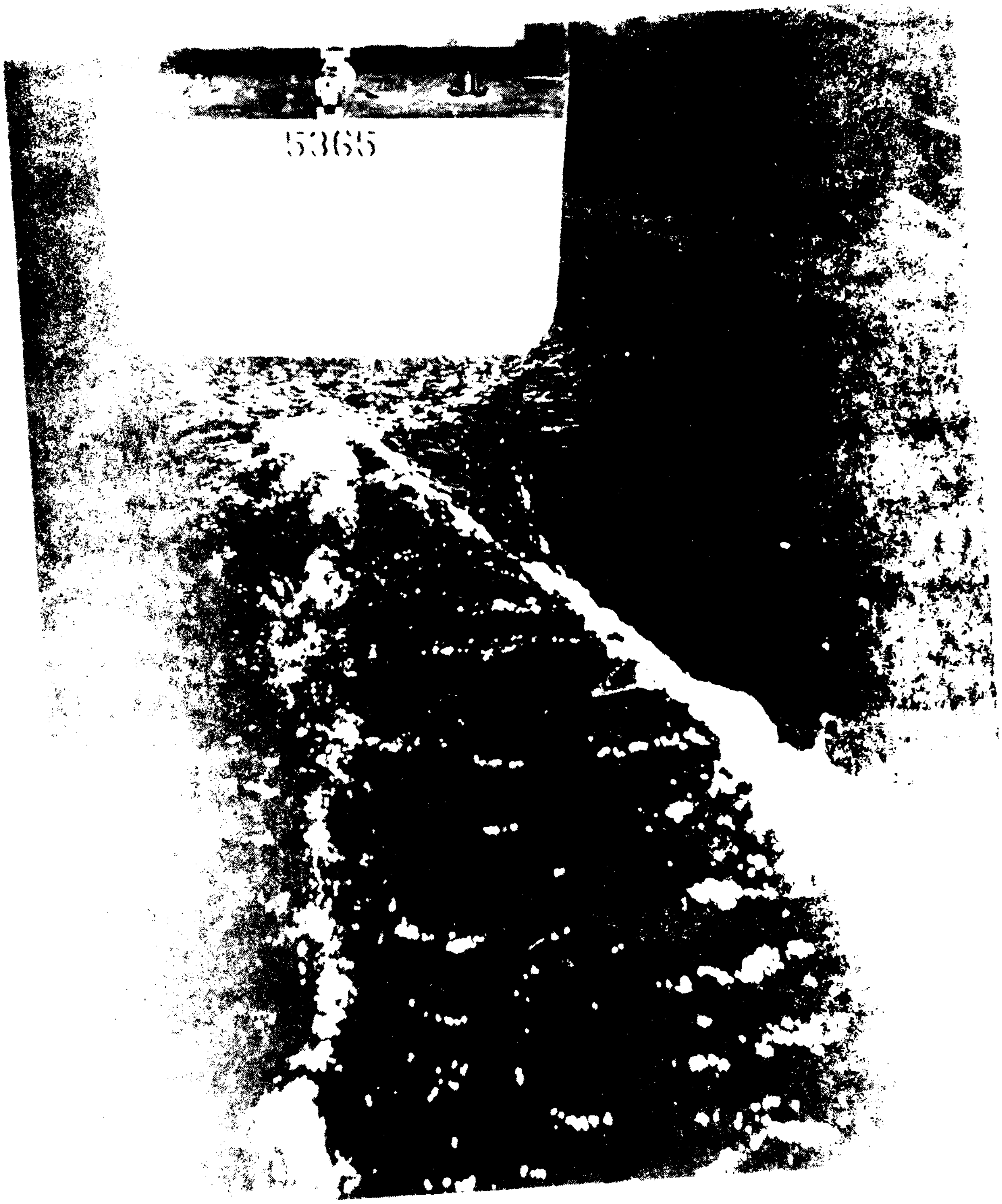


Figure 9 - Stern Flow for the R/V ATHENA, Fixed at Zero Trim and Sinkage at Froude Number 0.28, Model 5365



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Froude Number [illegible]

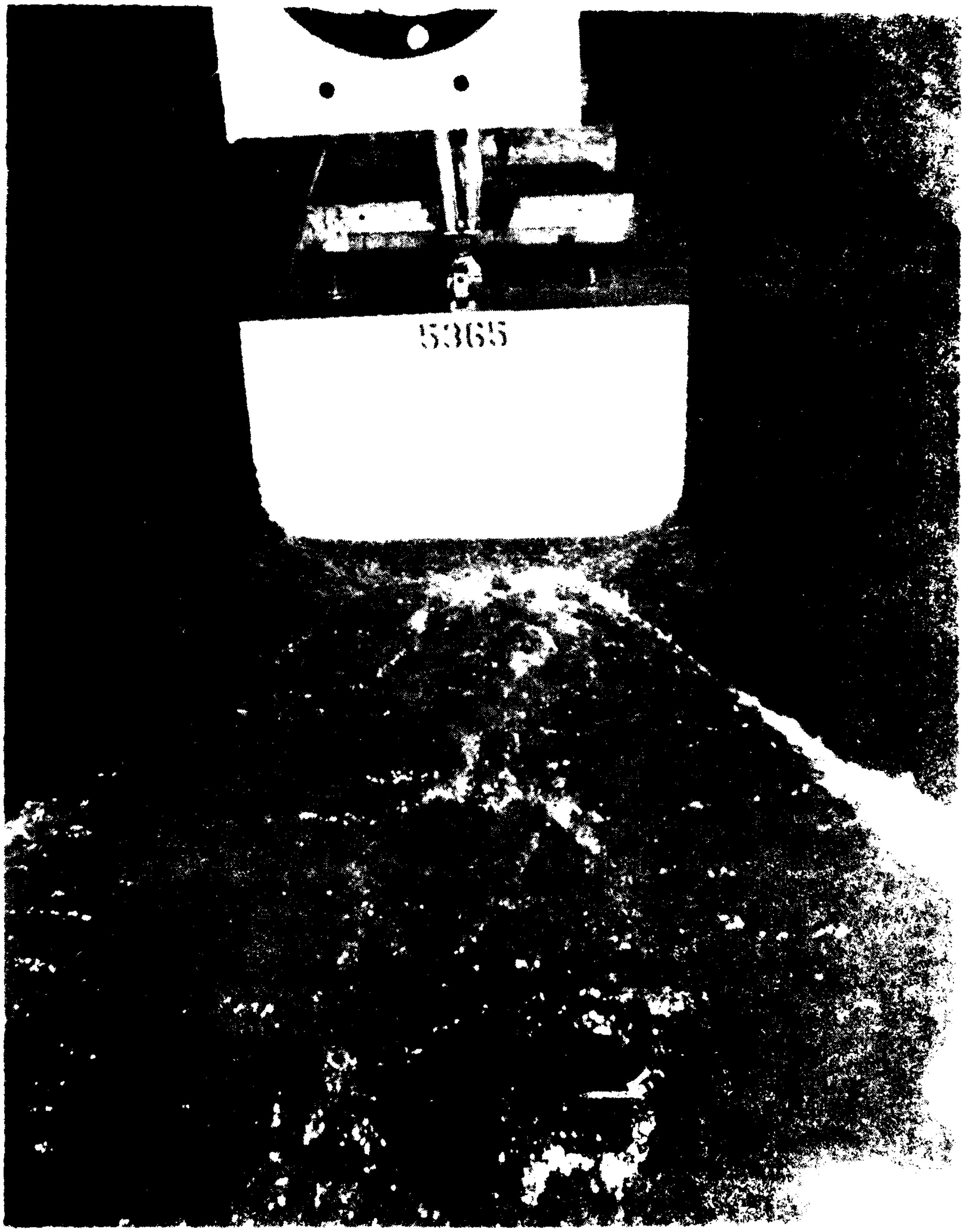

Figure 11 – Stern [illegible] for the R/V ATHENA, [illegible] Sidewise at Froude Number [illegible].31, [illegible]

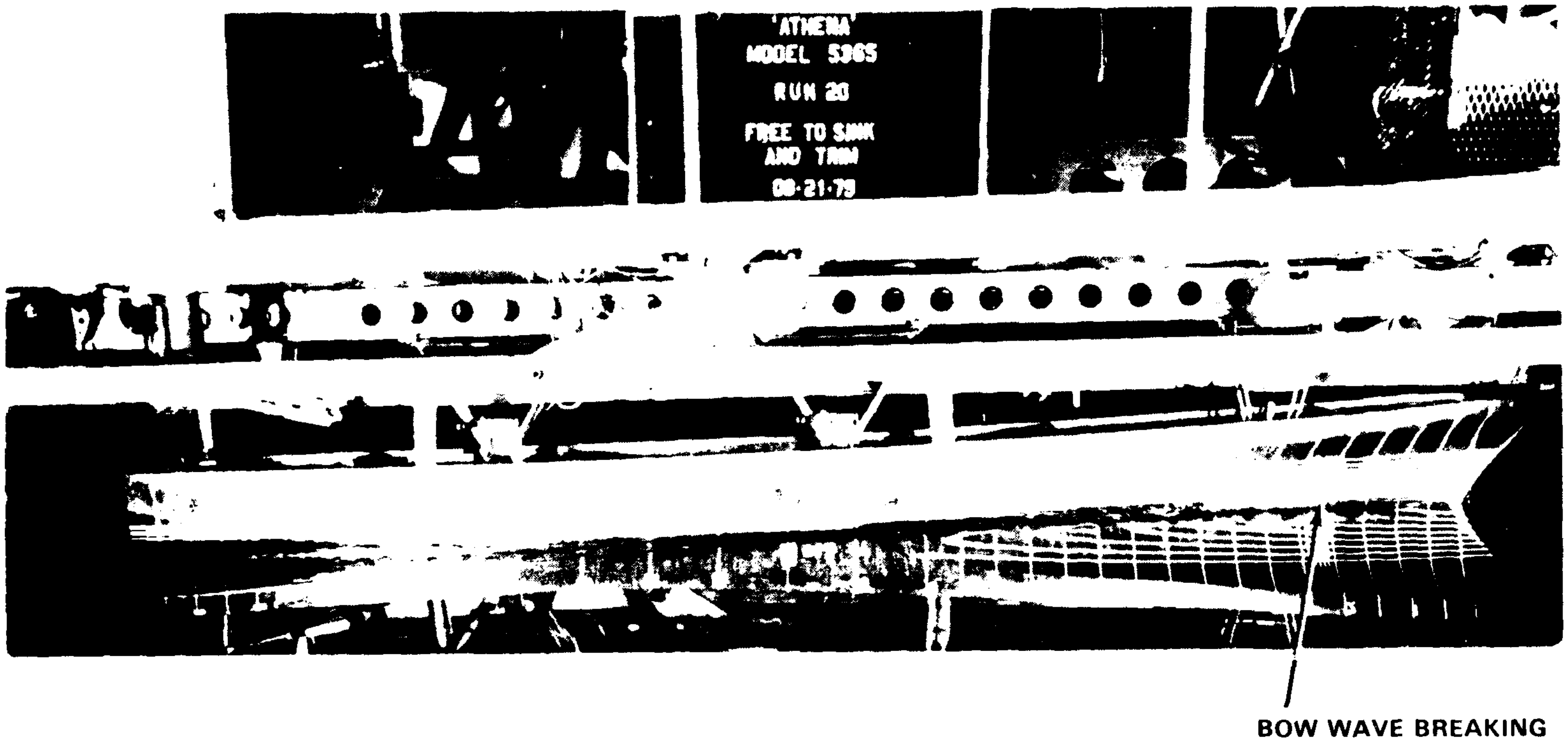

Figure 12 - Wave Profile for the R/V ATHENA, Free to Sink and Trim at Froude Number 0.48, Model 5365

Figure 13a - Model Free to Sink and Trin

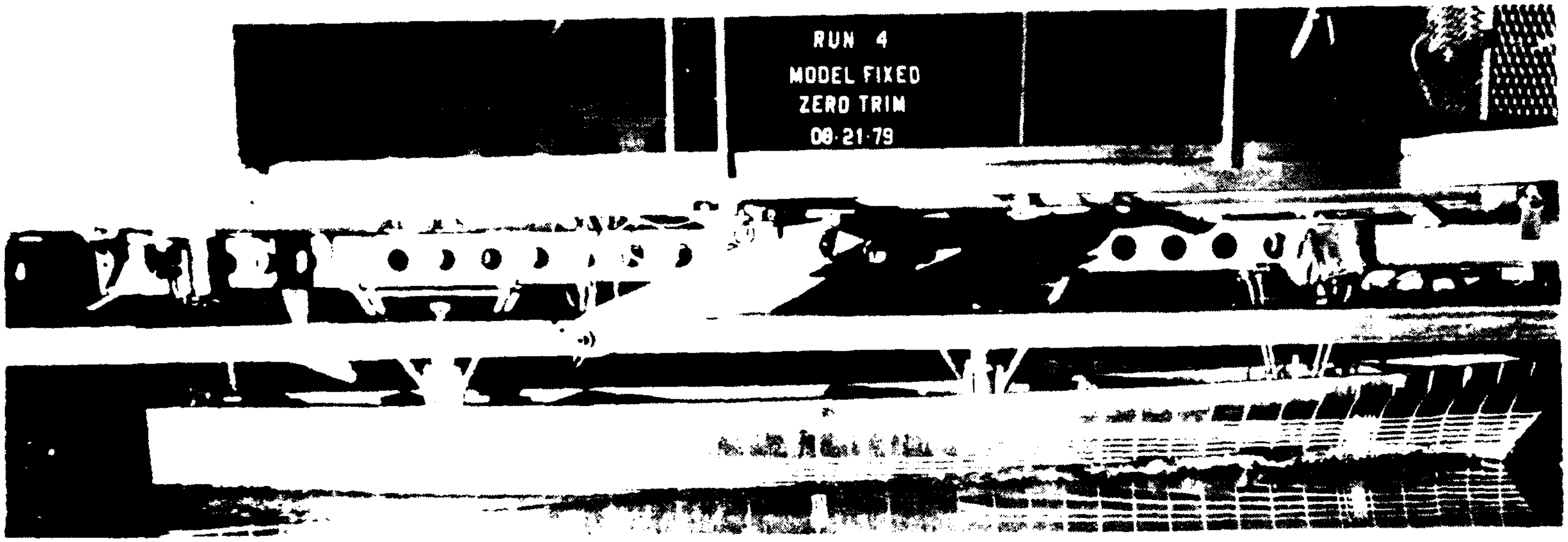

Figure 13b - Model Fixed at Zero Trim and Sinkage

Figure 13 - Wave Profiles for the R/V ATHENA at Froude Number 0.57 in Two Conditions of Trim, Model 5365

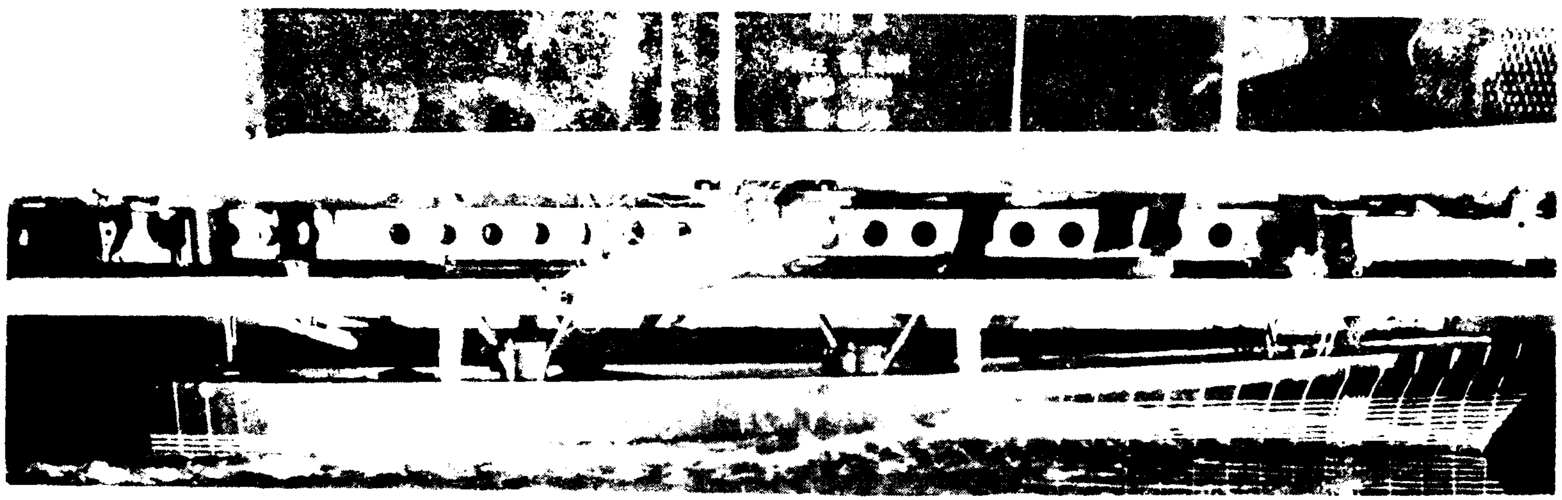

Figure 14a - Model Free to Sink and Trim

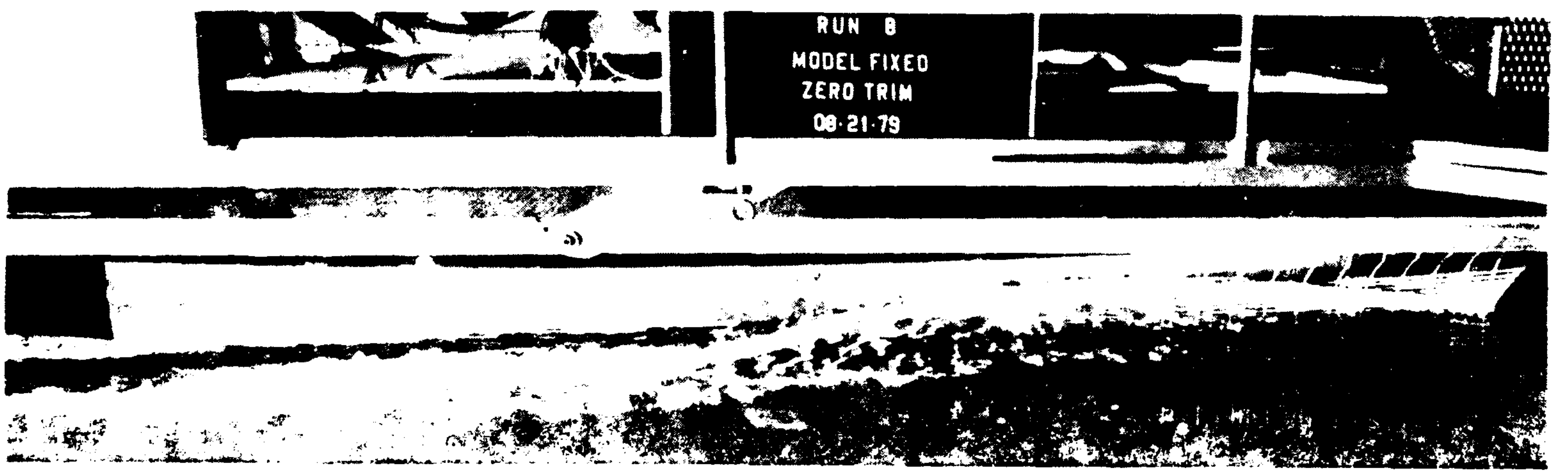

Figure 14b - Model Fixed at Zero Trim and Sinkage

Figure 14 - Wave Profiles for the [illegible] at Froude Number [illegible] Trim, Model [illegible]

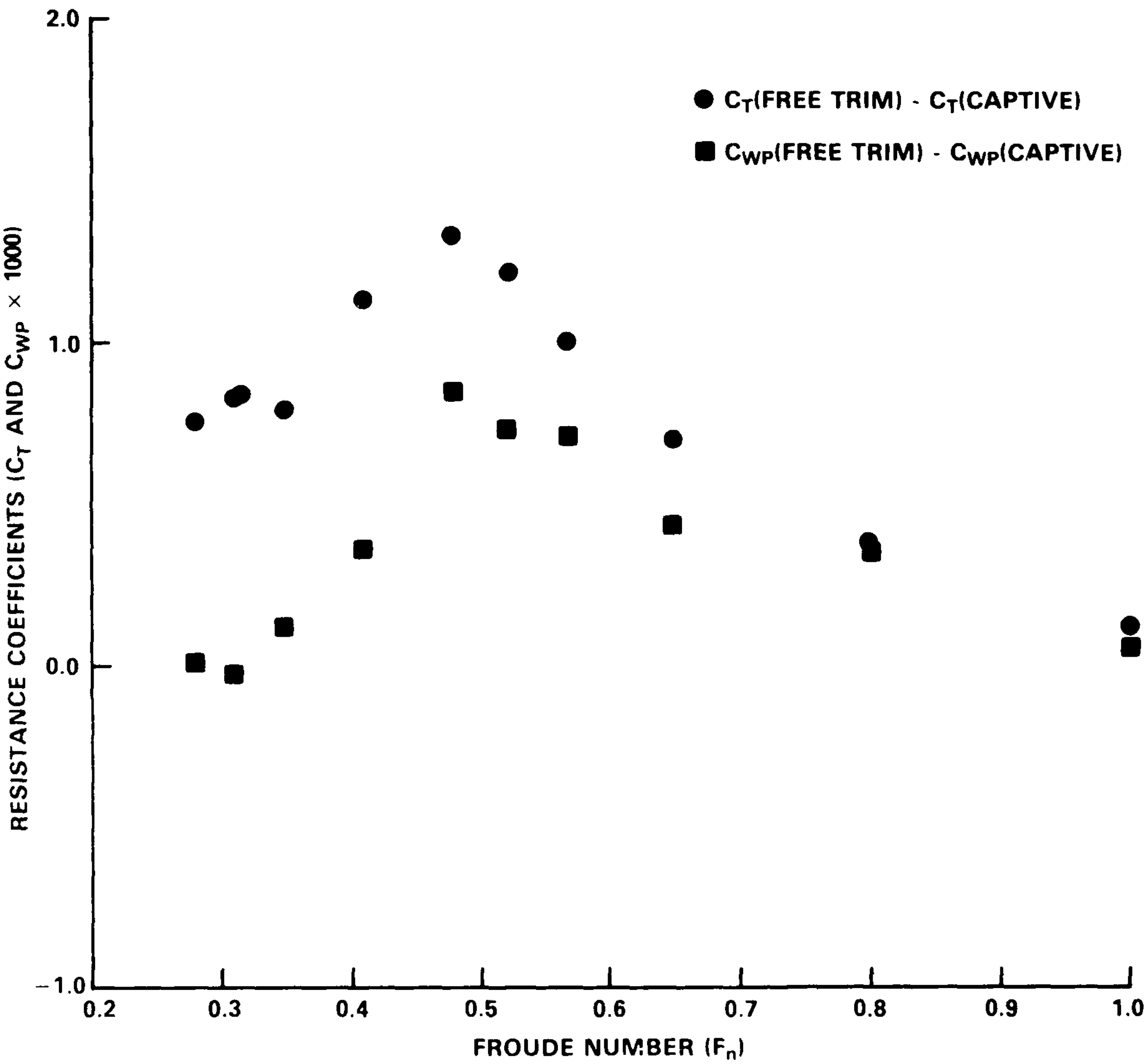

Figure 15 - Effect of Sinkage and Trim on the Total and Wave Pattern Resistance Coefficients for R/V ATHENA, as Determined from Experiments with Model 5365

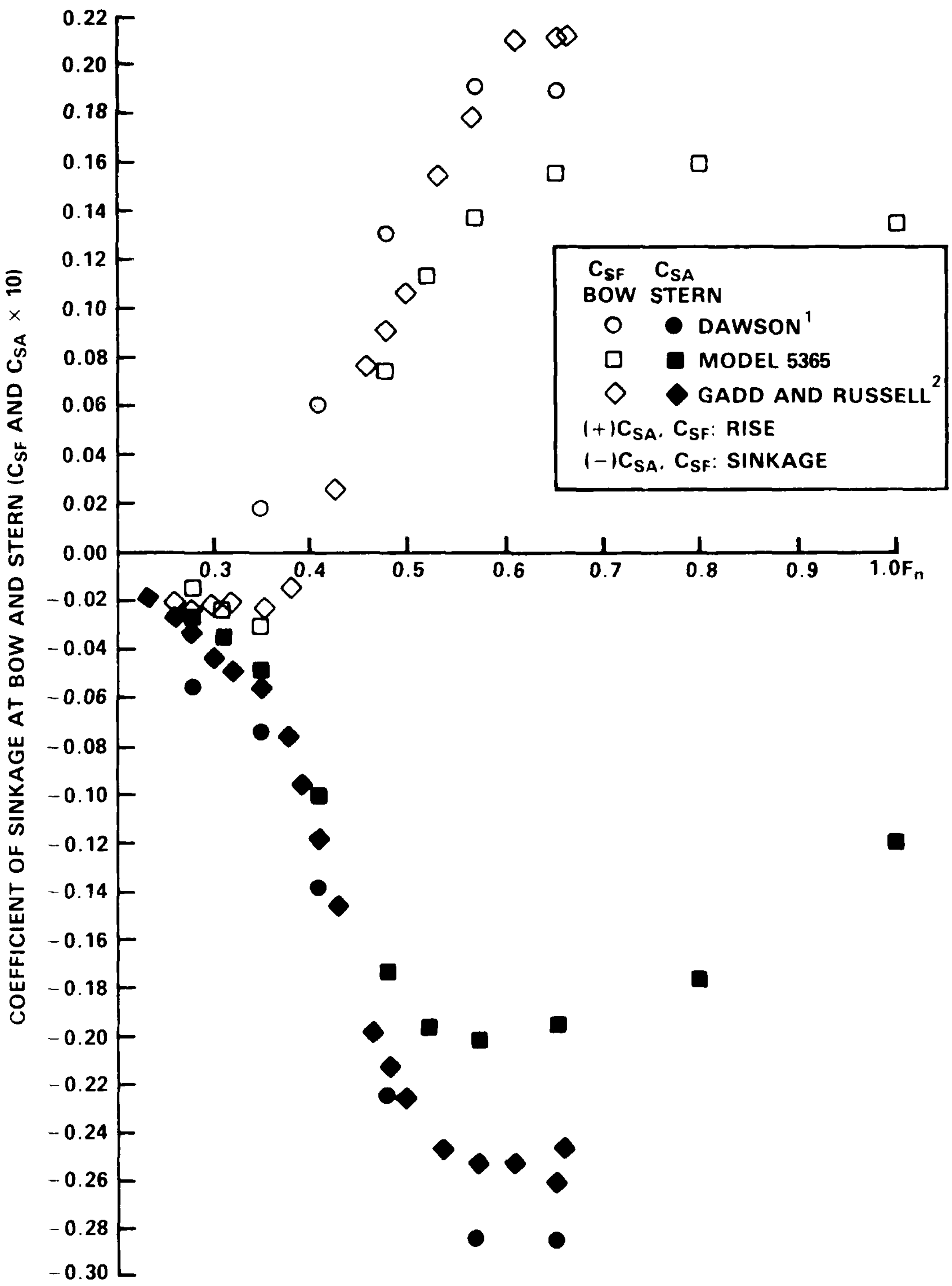

Figure 16 - Coefficients of Bow and Stern Sinkage for R/V ATHENA, as Determined from Experiments with Model 5365 and Compared to the Results of Dawson and Gadd and Russell

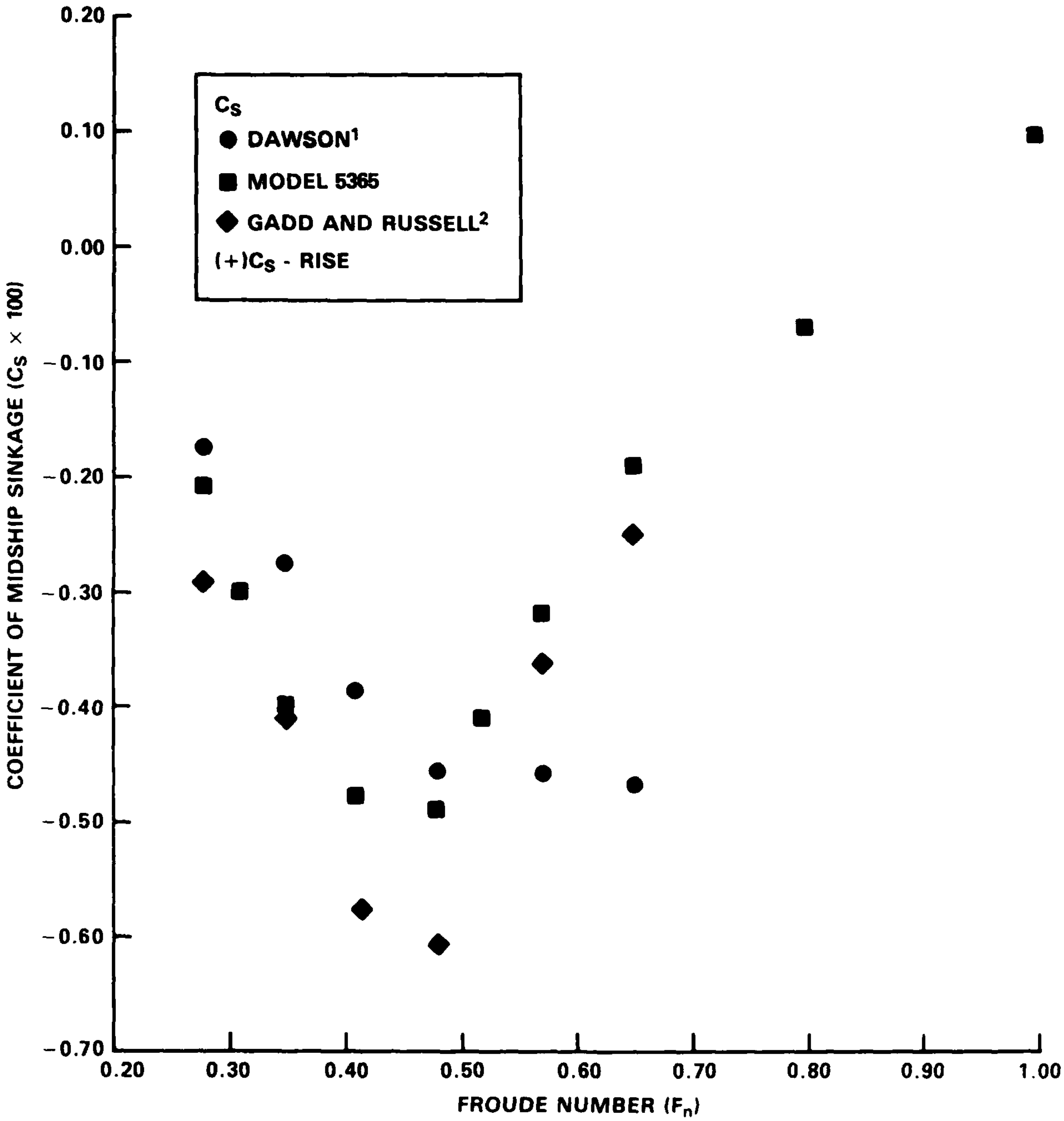

Figure 17 - Coefficient of Midship Sinkage for R/V ATHENA, as Determined from Experiments with Model 5365 and Compared to the Results of Dawson and Gadd and Russell

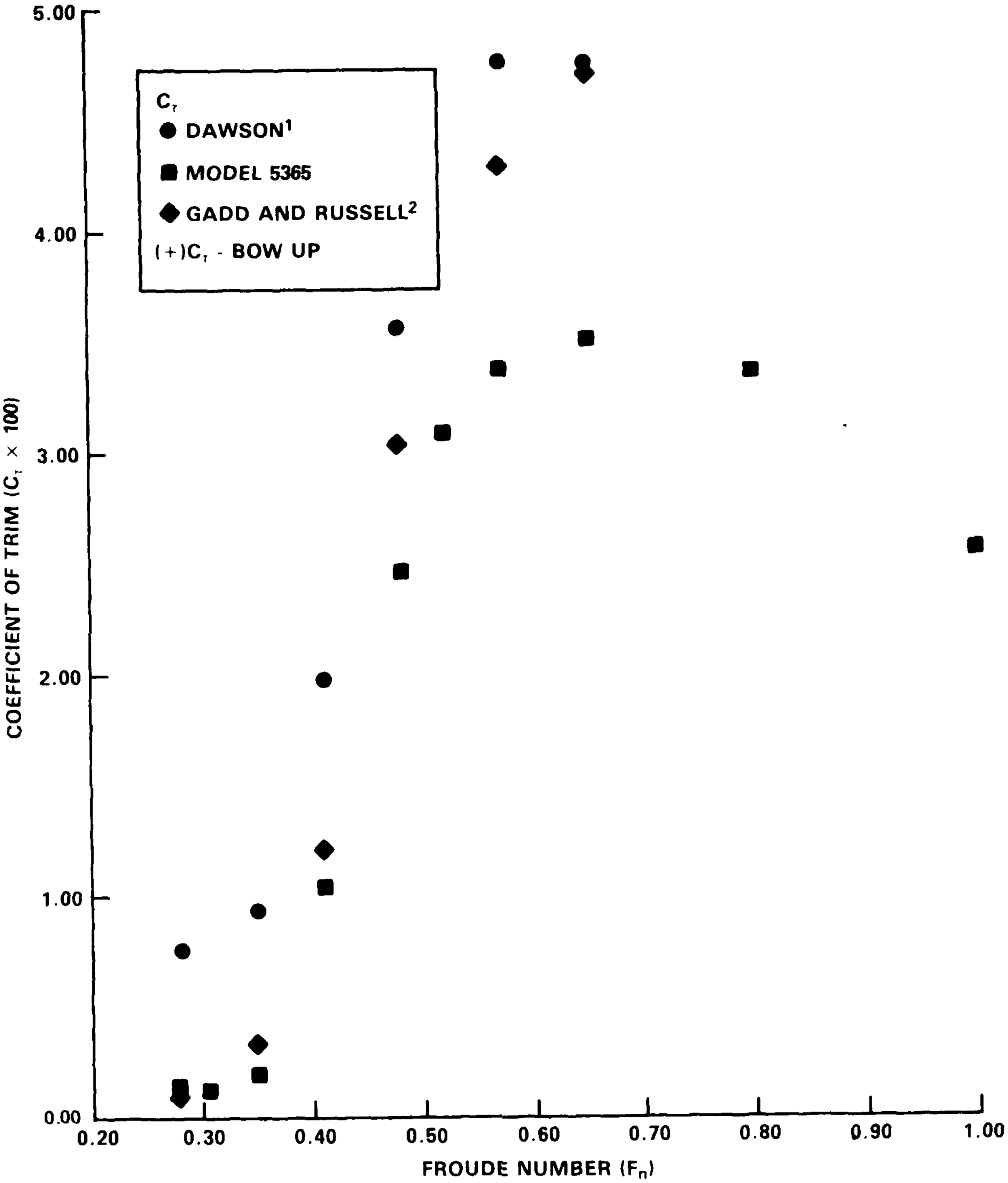

Figure 18 - Coefficient of Trim for R/V ATHENA, as Determined from Experiments with Model 5365 and Compared to the Results of Dawson and Gadd and Russell

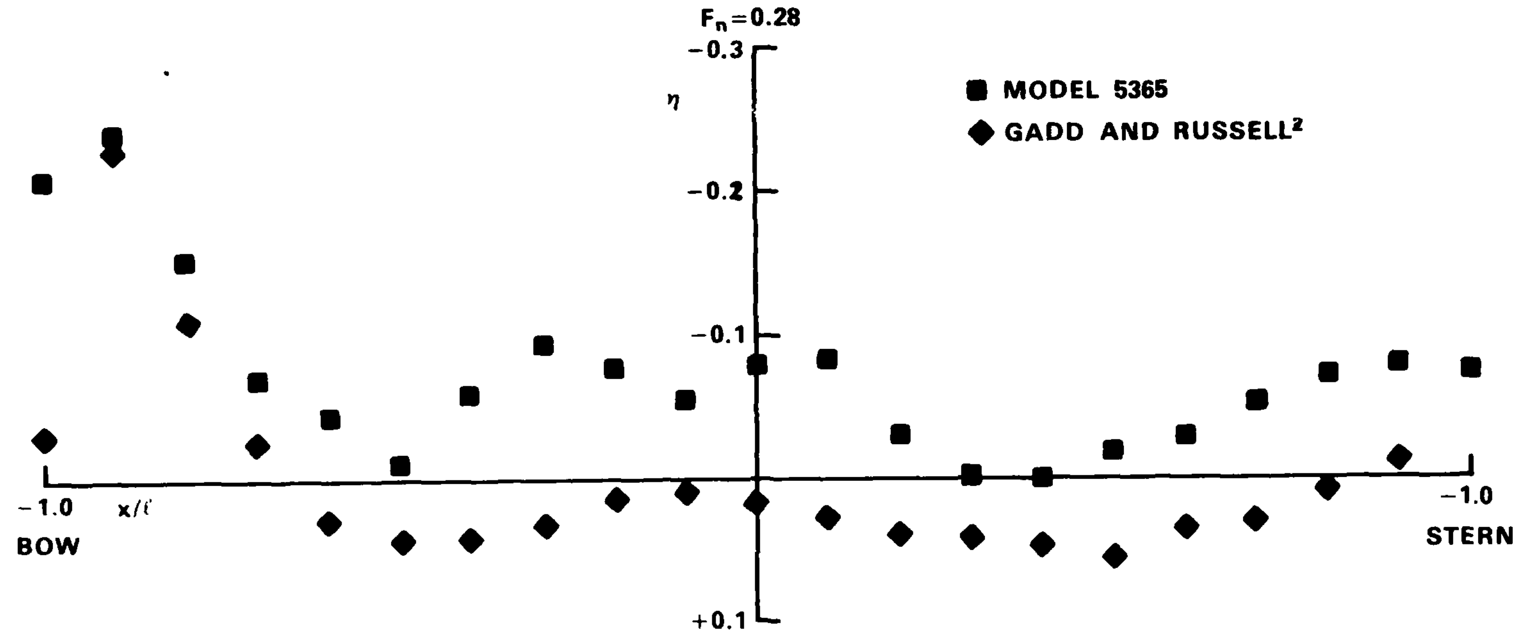

Figure 19 - Nondimensional Wave Profile Heights Along the Hull for R/V ATHENA, Free to Sink and Trim, as Determined from Experiments with Model 5365 at Froude Number 0.28

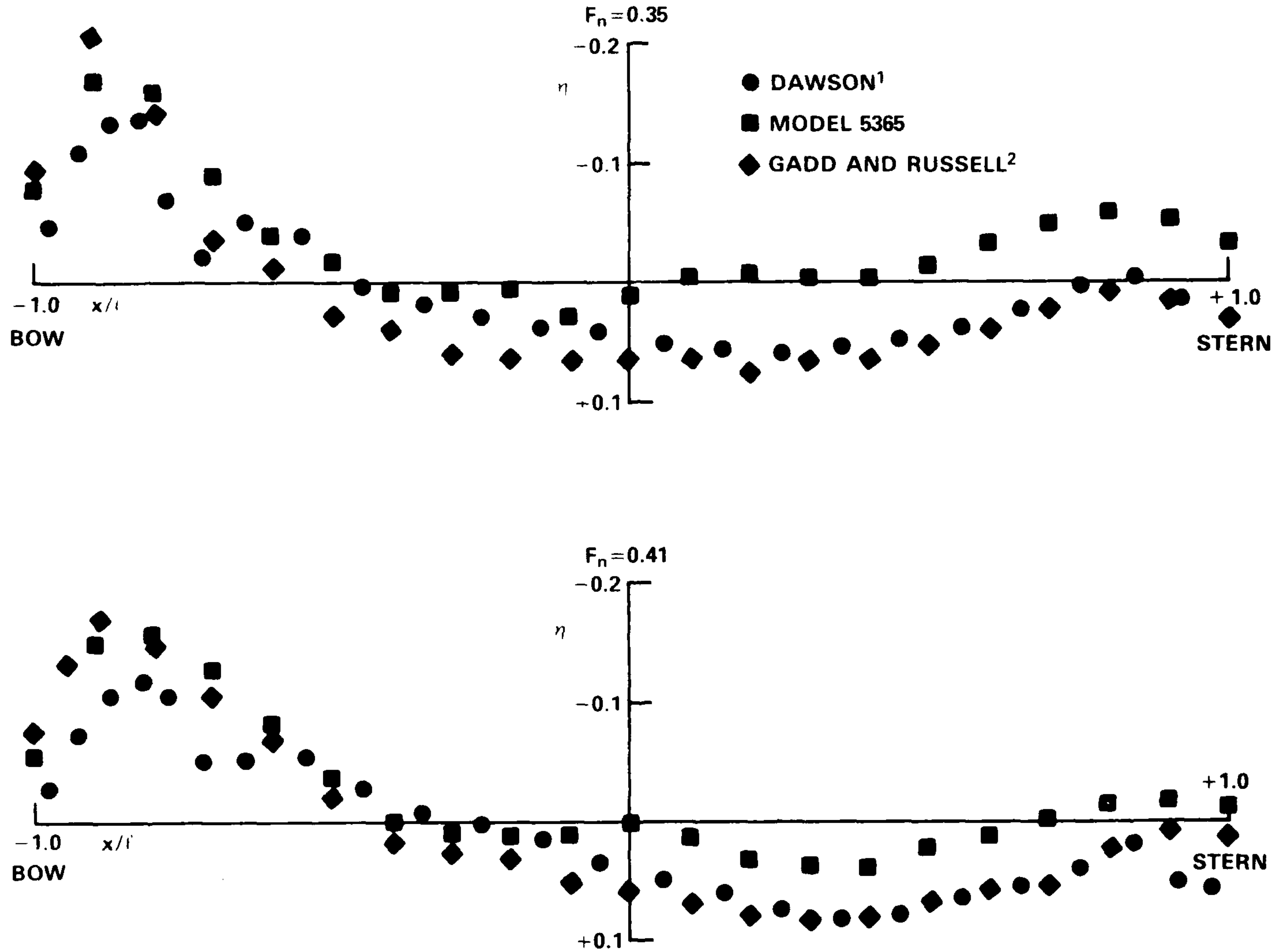

Figure 20 - Nondimensional Wave Profile Heights Along the Hull for R/V ATHENA, Free to Sink and Trim, as Determined from Experiments with Model 5365 at Froude Numbers 0.35 and 0.41

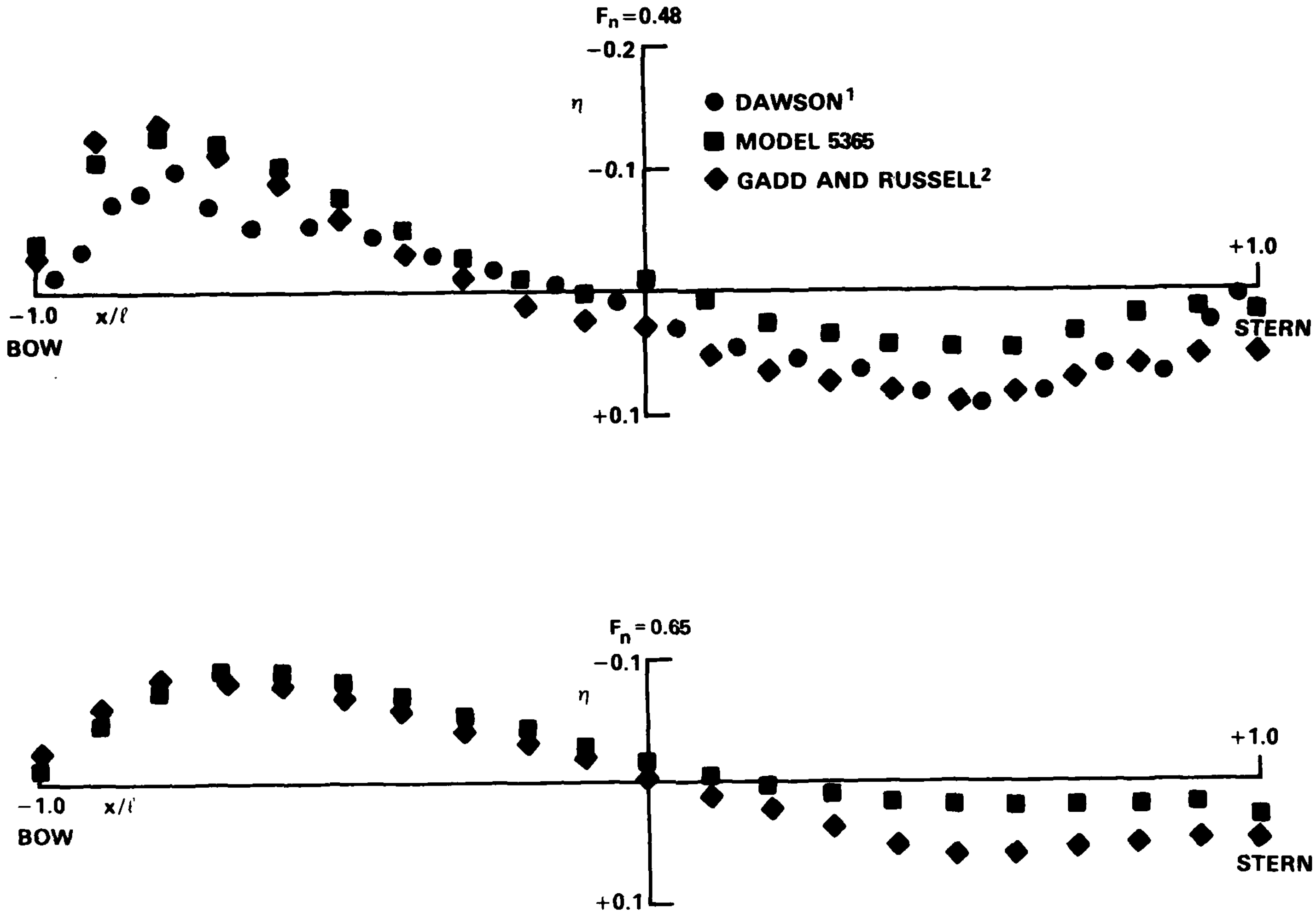

Figure 21 - Nondimensional Wave Profile Heights Along the Hull for R/V ATHENA, Free to Sink and Trim, as Determined from Experiments with Model 5365 at Froude Numbers 0.48 and 0.65

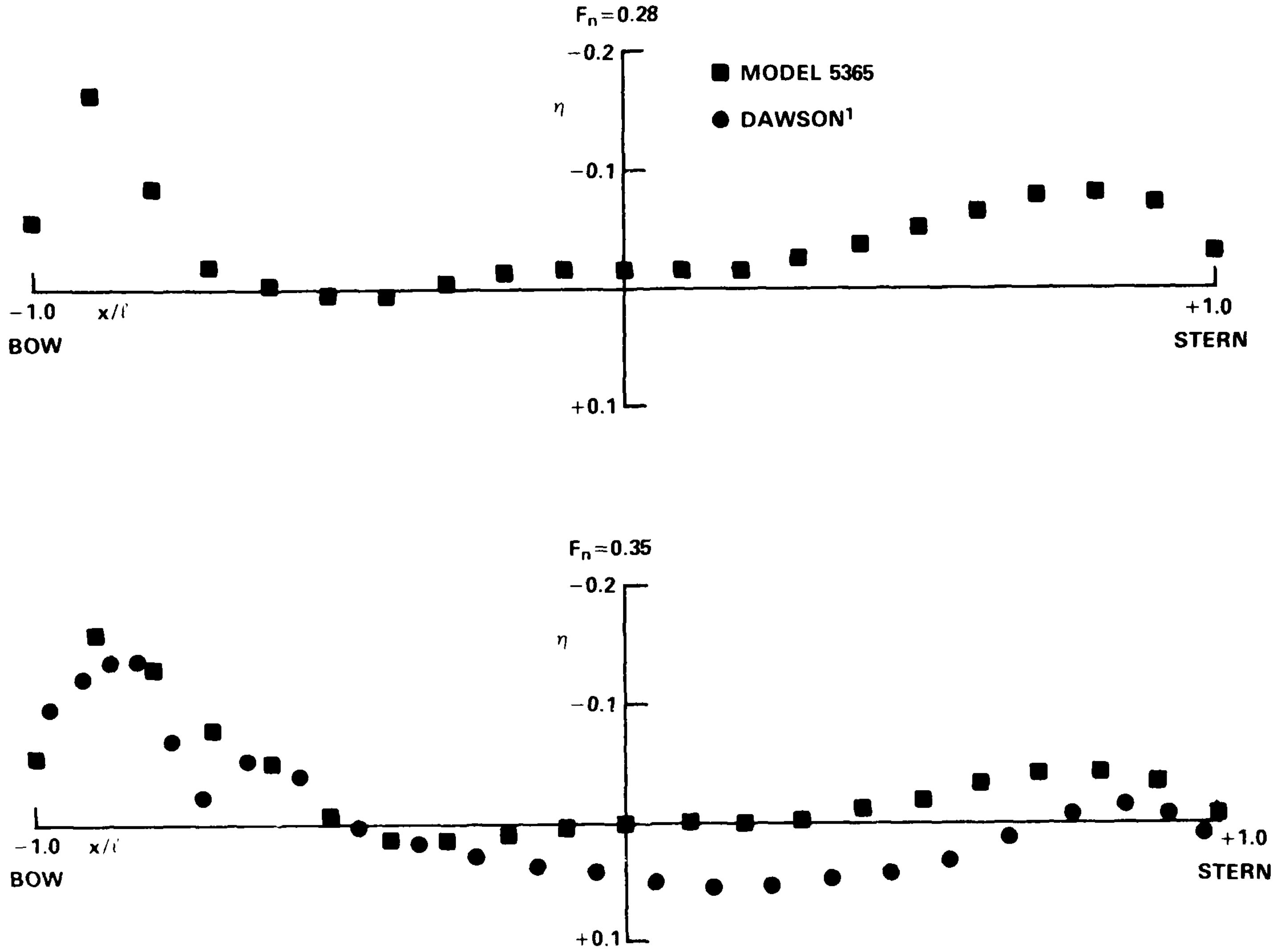

Figure 22 – Nondimensional Wave Profile Heights Along the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Numbers 0.28 and 0.35

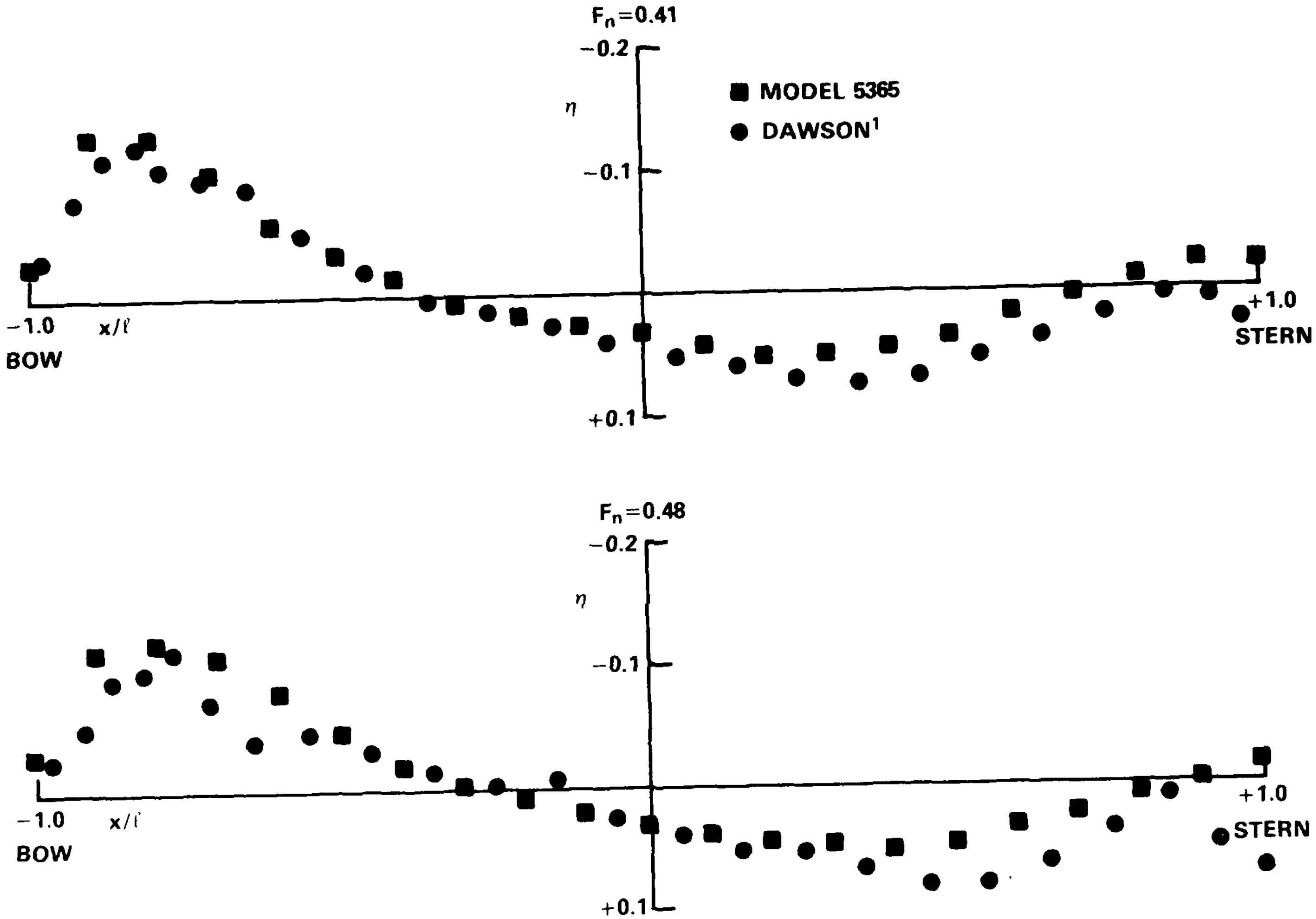

Figure 23 - Nondimensional Wave Profile Heights Along the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Numbers 0.41 and 0.48

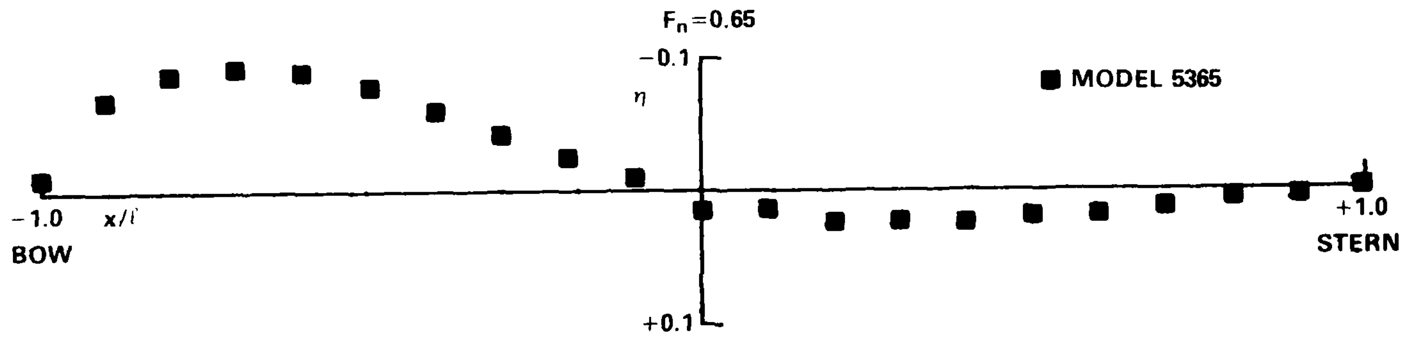

Figure 24 - Nondimensional Wave Profile Heights Along the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Number 0.65

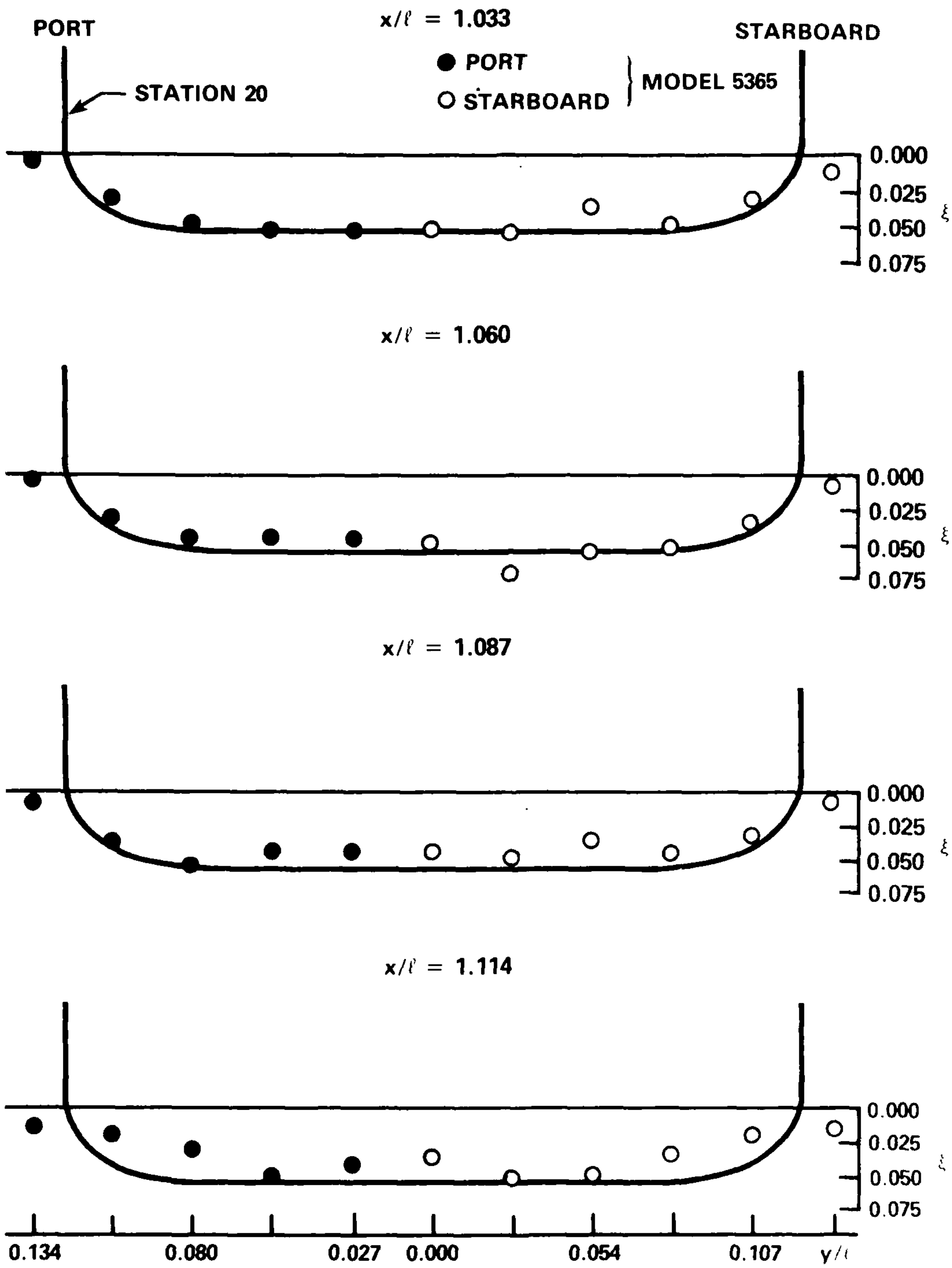

Figure 25 - Nondimensional Wave Heights Behind the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Number 0.48, x/ℓ = 1.033, 1.060, 1.087, and 1.114

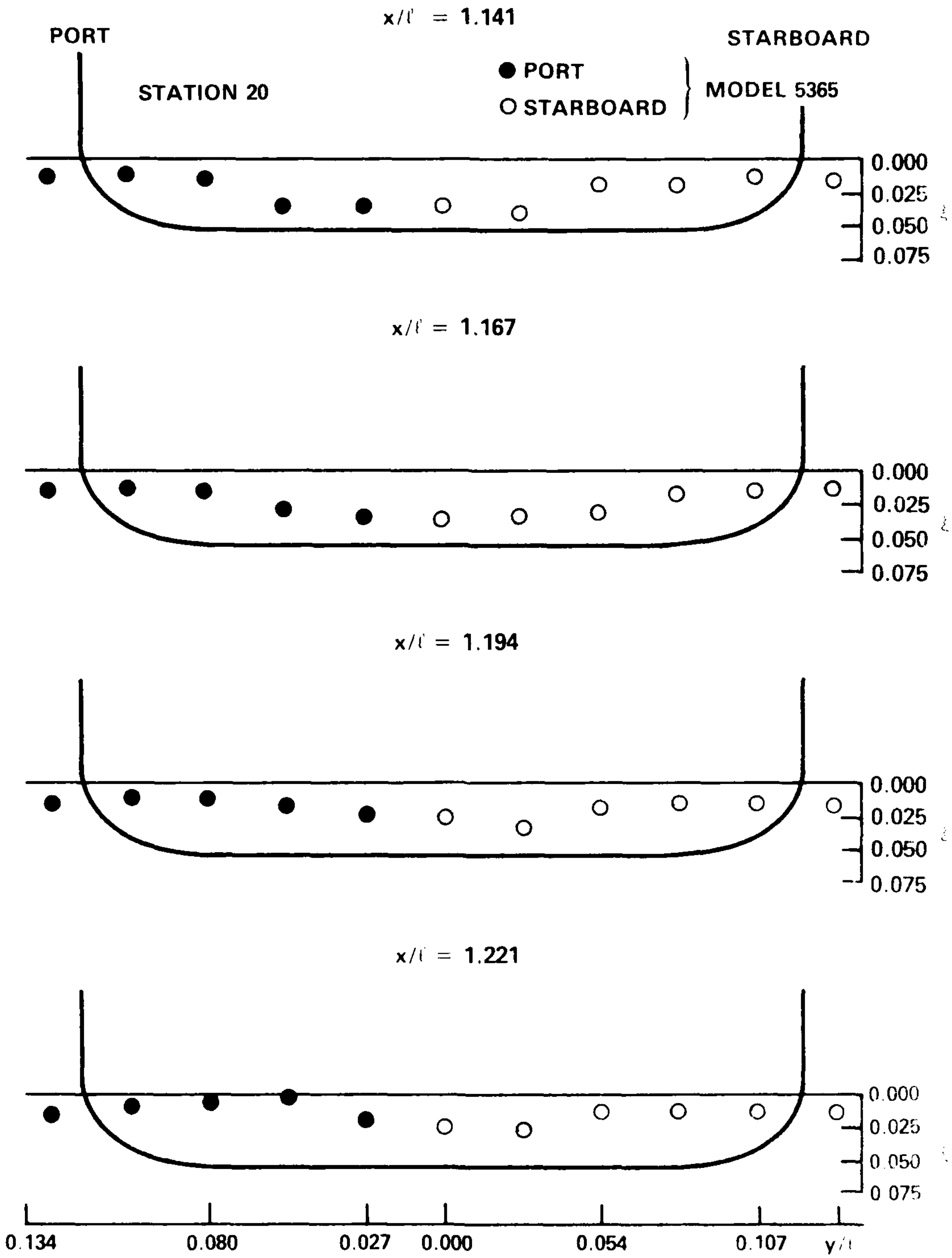

Figure 26 – Nondimensional Wave Heights Behind the Hull for R/V ATHENA, [illegible] at Zero Trim and Sinkage, as Determined from Experiments with Model [illegible] at Froude Number 0.48, x/ℓ = 1.141, 1.167, 1.194, and 1.221

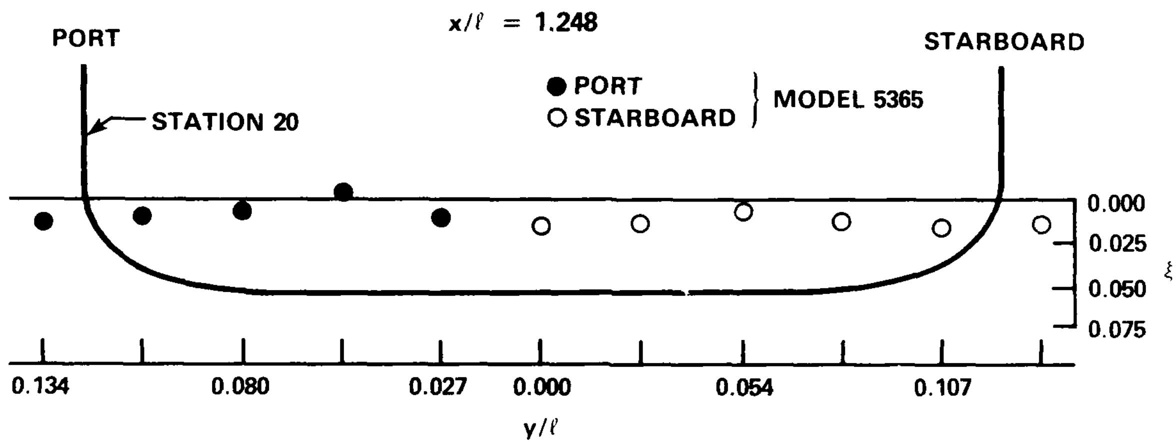

Figure 27 - Nondimensional Wave Heights Behind the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Number 0.48, $x/\ell = 1.248$

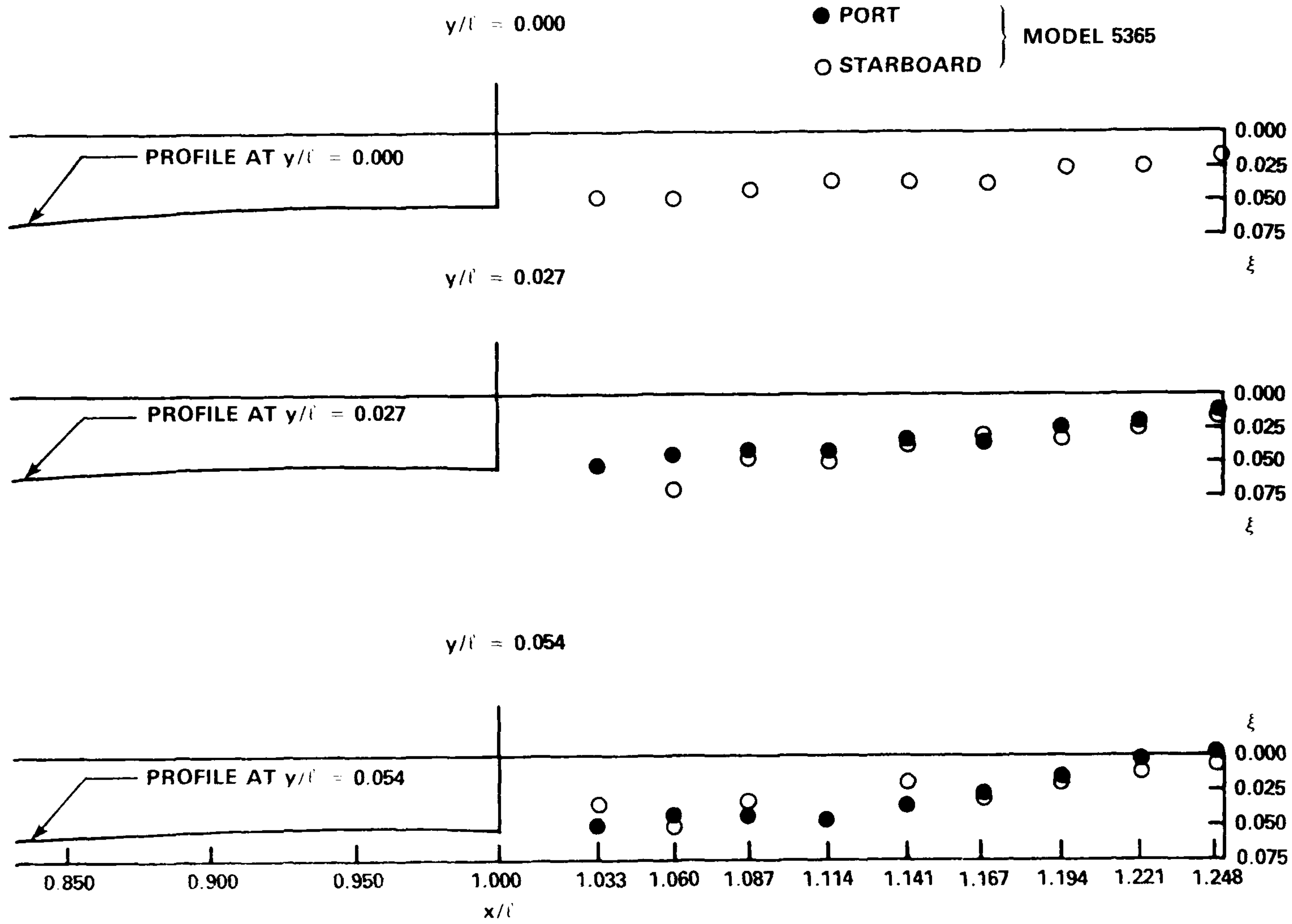

Figure [illegible] - Nondimensional Wave Heights Behind the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Number 0.48, y/ℓ = 0.000, 0.027, and 0.054

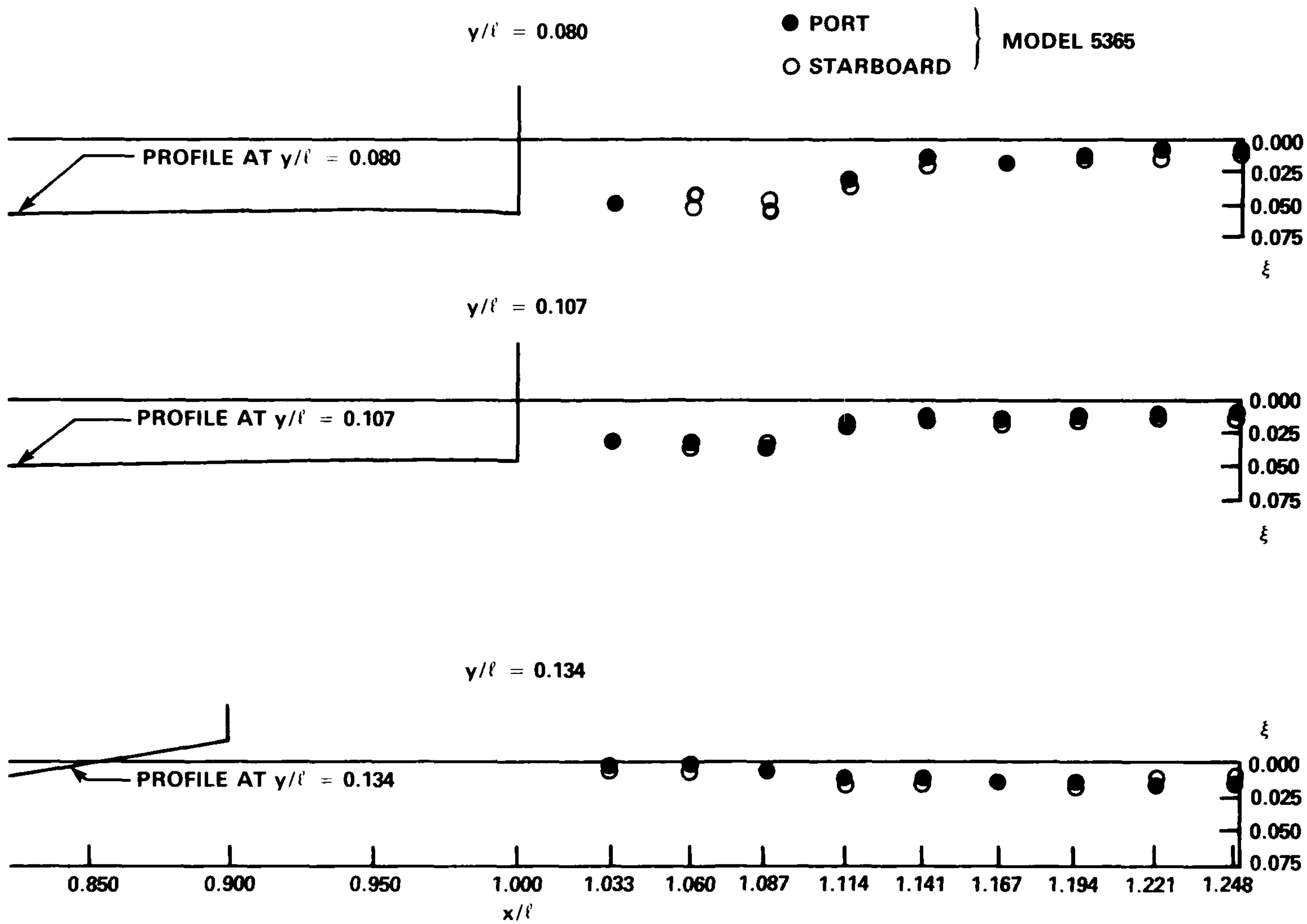

Figure 29 - Nondimensional Wave Heights Behind the Hull for R/V ATHENA, Fixed at Zero Trim and Sinkage, as Determined from Experiments with Model 5365 at Froude Number 0.48, y/ℓ = 0.080, 0.107, and 0.134

TABLE 1 - HULL FORM PARAMETERS FOR R/V ATHENA AND PRINCIPAL DIMENSIONS FOR MODEL 5365

B/L_{pp} = 0.1332 (Beam at midships)

B_{max}/L_{pp} = 0.1470 (Maximum beam at station 14)

H/L_{pp} = 0.0321 (Measured from baseline)

C_B = 0.4775

C_{PR} = 0.6680

C_X = 0.7147

C_S = 0.6607

L/L_{pp} = 1.000 (Where L = LWL)

L = 18.667 ft (5.690 m)

H = 0.599 ft (0.183 m)

S = 45.450 ft^2 (4.222 m^2)

B_{max} = 2.744 ft (0.836 m)

TABLE 2 - OFFSETS FOR THE HIGH-SPEED HULL, ATHENA

Station	Tangency	Offsets*						
		0.125 H	0.25 H	0.50 H	0.75 H	1.00 H	1.25 H	1.50 H
FP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0048	0.0185	0.0347
1/2	0.0000	0.0000	0.0246	0.0359	0.0451	0.0570	0.0758	0.0989
1	0.0000	0.0000	0.0525	0.0818	0.0959	0.1110	0.1354	0.1637
1 1/2	0.0000	0.0000	0.0838	0.1292	0.1462	0.1675	0.1945	0.2267
2	0.0000	0.0000	0.1162	0.1766	0.2035	0.2257	0.2542	0.2886
3	0.0000	0.0377	0.1955	0.2813	0.3104	0.3398	0.3711	0.4081
4	0.0000	0.1029	0.2849	0.3891	0.4218	0.4478	0.4761	0.5129
5	0.0000	0.1972	0.3989	0.4992	0.5280	0.5643	0.5776	0.6078
6	0.0000	0.3036	0.4972	0.6009	0.6246	0.6462	0.6700	0.6990
7	0.0000	0.4305	0.6190	0.6934	0.7070	0.7263	0.7476	0.7703
8	0.0000	0.5918	0.7262	0.7783	0.7830	0.7967	0.8156	0.8345
9	0.0000	0.7410	0.8346	0.8517	0.8448	0.8568	0.8807	0.8869
10	1.0000	0.8868	0.9240	0.9136	0.9002	0.9065	0.9177	0.9199
11	1.0000	1.0000	1.0000	0.9671	0.9420	0.9381	0.9457	0.9488
12	1.0000	0.8353	0.9519	1.0000	0.9762	0.9660	0.9684	0.9699
13	0.0000	0.4580	0.8424	1.0000	0.9942	0.9872	0.9875	0.9888
14	0.0000	0.0000	0.5765	0.9801	1.0000	1.0000	1.0000	1.0000
15	0.0000	0.0000	0.0581	0.9113	0.9865	0.9939	0.9946	0.9953
16	0.0000	0.0000	0.0000	0.7645	0.9575	0.9751	0.9791	0.9799
17	0.0000	0.0000	0.0000	0.4870	0.9227	0.9478	0.9505	0.9517
18	0.0000	0.0000	0.0000	0.0871	0.8731	0.9108	0.9147	0.9134
18 1/2	0.0000	0.0000	0.0000	0.0000	0.8545	0.8926	0.8920	0.8899
19	0.0000	0.0000	0.0000	0.0000	0.8345	0.8695	0.8711	0.8669
19 1/2	0.0000	0.0000	0.0000	0.0000	0.8068	0.8477	0.8461	0.8416
20 (AP)	0.0000	0.0000	0.0000	0.0000	0.8023	0.8289	0.8216	0.8168
Max. half beam	0.0073	0.3538	0.5431	0.7937	0.9424	1.0000	1.0170	1.0303

*From drawings for Model 5365.

TABLE 3 - COMPARISON OF STERN GEOMETRY FOR R/V ATHENA

References for Obtaining Values of Geometry	Offsets, y/B_{max}			Heights above the Baseline, z/H	
	WL = 0.50	WL = 0.75	WL = 1.00	Centerline 0.00	Buttock 0.50
Station 18					
DTNSRDC Drawing, no wedge	0.036*	0.416	0.456	0.482**	0.579***
DTNSRDC Drawing, with wedge	0.036	0.414	0.456	0.482	0.589
Reference 1	0.035	0.412	0.455	----	----
Reference 2	0.041	0.414	0.457	0.486	0.584
Station 19					
DTNSRDC Drawing, no wedge	0.000	0.398	0.435	0.565	0.610
DTNSRDC Drawing, with wedge	0.000	0.396	0.435	0.576	0.622
Reference 1	0.000	0.393	0.435	-----	-----
Reference 2	-----	-----	-----	0.581	0.628
Station 19-1/2					
DTNSRDC Drawing, no wedge	0.000	0.383	0.424	0.613	0.631
DTNSRDC Drawing, with wedge	0.000	0.383	0.424	0.613	0.631
Reference 1	0.000	0.380	0.424	-----	-----
Station 20					
DTNSRDC Drawing, no wedge	0.000	0.379	0.413	0.638	0.642
DTNSRDC Drawing, with wedge	0.000	0.379	0.413	0.610	0.610
Reference 1	0.000	0.379	0.414	-----	-----
Reference 2	0.000	0.377	0.412	0.628	0.638

* Nondimensional offset values are given for y/B_{max} at the 1.00 water level

** Nondimensional values at $y/B_{max} = 0.00$

*** NOndimensional values at $y/B_{max} = 0.25$

TABLE 4 - COEFFICIENTS OF TOTAL, RESIDUARY, AND WAVE PATTERN RESISTANCES FOR R/V ATHENA FREE TO SINK AND TRIM, AS DETERMINED FROM EXPERIMENTS WITH MODEL 5365

F_n	$C_T \times 1000$	$C_R \times 1000$	F_n	$C_{WP} \times 1000$
0.280	5.531	2.655	0.282	0.465
0.310	5.357	2.530	0.312	0.700
0.312	5.344	2.520	0.351	0.985
0.350	5.030	2.260	0.412	1.546
0.410	5.498	2.800	0.448	1.912
0.480	5.774	3.145	0.484	2.192
0.520	5.629	3.033	0.521	2.083
0.570	5.347	2.790	0.570	1.851
0.650	4.924	2.420	0.653	1.407
0.800	4.387	1.963	0.800	0.931
1.000	4.008	1.666	1.000	0.325

TABLE 5 - COEFFICIENTS OF TOTAL, RESIDUARY, AND WAVE PATTERN RESISTANCES FOR R/V ATHENA FIXED AT ZERO TRIM AND SINKAGE, AS DETERMINED FROM EXPERIMENTS WITH MODEL 5365

F_n	$C_T \times 1000$	$C_R \times 1000$	F_n	$C_{WP} \times 1000$
0.280	4.774	1.868	0.281	0.451
0.310	4.550	1.723	-----	-----
0.312	4.536	1.712	0.312	0.734
0.350	4.239	1.469	0.350	0.858
0.410	4.357	1.659	0.412	1.182
0.480	4.437	1.808	0.484	1.342
0.520	4.406	1.810	0.521	1.350
0.570	4.345	1.788	0.570	1.150
0.650	4.219	1.715	0.651	0.968
0.800	4.000	1.576	0.799	0.584
1.000	3.887	1.545	0.988	0.258

TABLE 6 - COEFFICIENTS OF SINKAGE AND TRIM FOR R/V ATHENA, AS DETERMINED FROM EXPERIMENTS WITH MODEL 5365

F_n	C_{sf} x 100	C_{sa} x 100	C_s x 100	C_T x 100
0.280	-0.15*	-0.27*	-0.21*	0.12
0.310	-0.24	-0.35	-0.30	0.11
0.312	-0.24	-0.36	-0.30	0.12
0.350	-0.30	-0.49	-0.40	0.19
0.410	0.30	-1.00	-0.48	1.04
0.480	0.75	-1.73	-0.49	2.48
0.520	1.14	-1.96	-0.41	3.10
0.570	1.38	-2.01	-0.32	3.39
0.650	1.57	-1.95	-0.19	3.52
0.800	1.62	-1.76	-0.07	3.38
1.000	1.38	-1.18	0.10	2.56

* Minus values of C_s, C_{sa}, and C_{sf} mean "below calm water draft (sinkage).

TABLE 7 - NONDIMENSIONAL WAVE PROFILE HEIGHTS (η) ALONG THE HULL FOR R/V ATHENA FREE TO SINK AND TRIM, AS DETERMINED FROM EXPERIMENTS WITH MODEL 5365

	η				
Station	F_n = 0.28	0.35	0.41	0.48	0.65
FP	-0.218*	-0.079	-0.056	-0.040	-0.012
1	-0.239	-0.171	-0.150	-0.109	-0.046
2	-0.156	-0.161	-0.157	-0.130	-0.076
3	-0.080	-0.090	-0.128	-0.123	-0.093
4	-0.042	-0.041	-0.084	-0.102	-0.093
5	-0.011	-0.019	-0.038	-0.078	-0.084
6	-0.057	-0.010	-0.002	-0.052	-0.071
7	-0.092	-0.008	0.007	-0.029	-0.058
8	-0.079	-0.006	0.011	-0.009	-0.044
9	-0.056	-0.029	0.010	0.002	-0.029
10	-0.080	-0.011	0.001	-0.008	-0.015
11	-0.083	-0.006	0.012	0.008	-0.004
12	-0.030	-0.009	0.032	0.030	0.006
13	0.000	-0.004	0.037	0.037	0.012
14	0.000	-0.004	0.037	0.043	0.015
15	-0.018	-0.016	0.023	0.045	0.018
16	-0.029	-00.35	0.010	0.048	0.018
17	-0.051	-00.050	0.006	0.035	0.018
18	-0.071	-00.59	0.018	0.021	0.018
19	-0.080	-0.056	0.020	0.015	0.018
AP	-0.076	-0.035	0.012	0.016	0.025

*Minus values of η mean "wave heights above the calm water free surface."

TABLE 8 - NONDIMENSIONAL WAVE PROFILE HEIGHTS (η) ALONG THE HULL FOR R/V ATHENA FIXED AT ZERO TRIM AND SINKAGE, AS DETERMINED FROM EXPERIMENTS WITH MODEL 5365

	η				
Station	F_n = 0.28	0.35	0.41	0.48	0.65
FP	-0.057*	-0.058	-0.027	-0.031	-0.011
1	-0.166	-0.160	-0.133	-0.116	-0.070
2	-0.085	-0.130	-0.132	-0.125	-0.088
3	-0.017	-0.077	-0.101	-0.110	-0.093
4	-0.003	-0.049	-0.061	-0.080	-0.090
5	-0.002	-0.006	-0.035	-0.047	-0.078
6	-0.006	0.014	-0.013	-0.019	-0.061
7	-0.005	0.015	0.006	-0.004	-0.042
8	-0.014	0.010	0.018	-0.007	-0.024
9	-0.016	0.004	0.024	-0.019	-0.010
10	-0.016	0.000	0.032	0.032	0.015
11	-0.014	0.000	0.043	0.038	0.014
12	-0.016	0.000	0.052	0.042	0.023
13	-0.024	-0.003	0.053	0.047	0.024
14	-0.038	-0.012	0.049	0.051	0.023
15	-0.051	-0.023	0.037	0.047	0.020
16	-0.066	-0.032	0.019	0.035	0.016
17	-0.077	-0.039	-0.002	0.022	0.012
18	-0.082	-0.042	-0.012	0.009	0.007
19	-0.072	-0.036	-0.021	-0.004	0.003
20	-0.030	-0.007	-0.021	-0.016	0.001

*Minus values of η mean "wave heights above calm water free surface".

TABLE 9 - NONDIMENSIONAL WAVE HEIGHTS BEHIND THE HULL OF R/V ATHENA (ζ) FIXED AT ZERO TRIM AND SINKAGE, AS DETERMINED FROM EXPERIMENTS WITH MODEL 5365, FROUDE NUMBER = 0.48

	ζ										
	PORT					℄	STARBOARD				
x/ℓ*	y/ℓ** = 0.134	0.107	0.080	0.054	0.027	0.000	0.027	0.054	0.080	0.107	0.134
1.033	0.004***	0.031	0.049	0.052	0.052	0.050	0.056	0.037	0.049	0.031	0.007
1.060	0.003	0.031	0.045	0.047	0.047	0.049	0.073	0.053	0.051	0.033	0.007
1.087	0.008	0.037	0.053	0.046	0.045	0.044	0.049	0.034	0.046	0.032	0.007
1.114	0.013	0.019	0.031	0.048	0.042	0.037	0.051	0.049	0.034	0.019	0.015
1.141	0.012	0.012	0.016	0.037	0.035	0.035	0.039	0.019	0.019	0.014	0.015
1.167	0.015	0.012	0.018	0.030	0.034	0.035	0.034	0.032	0.017	0.015	0.015
1.198	0.015	0.011	0.013	0.018	0.024	0.026	0.034	0.019	0.015	0.013	0.017
1.221	0.016	0.010	0.007	0.003	0.021	0.023	0.027	0.012	0.012	0.012	0.015
1.238	0.015	0.010	0.008	-0.004	0.012	0.016	0.015	0.007	0.012	0.017	0.015

* Values of $x/\ell > 1.000$ are distances behind the transom ($x/\ell = 1.000$).
** Values of $y/\ell > 0.000$ are distances in the transverse direction from the longitudinal center plane ($y/\ell = 0.000$).
*** Plus values of ζ mean "wave heights below the calm water free surface,"

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